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NOTE ON THE PRESENCE OF IODINE IN LARGE QUANTITIES OF SHEEP PITUITARY GLAND.

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Because of the similarity between the pituitary and the thyroid glands in their physiological action as well as their embryological history, the question as to whether the pituitary gland contains any iodine, the element generally conceded to be vitally important in the functioning of the thyroid, is still an important one.

In 1896 Baumann (1) examined human pituitaries for the presence of iodine always with negative results. Schnitzler (2) also examined human pituitary glands using larger amounts of the material and found iodine twice. In 1909 Wells (3) analyzed human pituitaries and recovered definite amounts of iodine. In 1911 Denis (4) examined human pituitary glands and found no iodine.

Wells suggested in his paper that his ability to find iodine in the glands he examined might have been due to the fact that iodine had previously been used on these patients either as medicants or in dressings and that the element might have been absorbed by the gland from these external sources.

Denis made a careful study of the history of the cases whose glands she examined and excluded the possibility of iodine having been used in any way. She was not able to detect any trace of the element.

The largest amount of material examined was by Schnitzler when he analyzed 19 and 24 gm. of pituitary. In both cases he found iodine. It has been suggested that the iodine may exist in the pituitary gland in such infinitesimally small amounts that only by the use of large quantities of material could it be detected. Therefore, an attempt was made in this laboratory to examine pituitary glands in larger amounts than had previously been used.

Pituitary Gland

Fresh sheep pituitary glands were obtained, trimmed, ground, dried, and powdered. The presence of iodine was determined by the Baumann-Riggs method. Three samples were examined, the first consisting approximately of 30 gm.; the second 50 gm.; and the third 100 gm. In none of these samples was any iodine detected. These findings corroborate the findings of Denis.

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2. Schnitzler, J., *Wien. klin. Woch.*, 1896, ix, 657.
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4. Denis, W., *J. Biol. Chem.*, 1911, ix, 363.

HEMATO-RESPIRATORY FUNCTIONS.*

III. THE FALLACY OF ASPHYXIAL ACIDOSIS.

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(Received for publication, June 1, 1920.)

One of the ideas basic in the physiology of today is that a deficiency of oxygen produces in the blood a slight, but in its effects highly potent, acidity. Araki² observed that partial asphyxia causes the appearance of lactic acid (lactates) in the urine, and this has been interpreted to indicate that, in the absence of an adequate supply of oxygen, a condition which would now be called acidosis tends to develop.

This interpretation of Araki's observation has gained support from the fact, now apparently well demonstrated, that the first step chemically in the production of energy in the animal body is anaerobic: sugar breaking down into lactic acid, which, as a second step and as a process of elimination rather than of energy production, is then oxidized to carbon dioxide. The increase of lactic acid in blood and urine after vigorous muscular work, as found by Ryffel,³ is thus apparently easily explained.

The hypothesis of asphyxial acidosis has seemed to fit in well also with the regulation of respiration by the chemical condition of the blood; for if the hormone of breathing is the CH of the blood, an increased production, or delayed destruction, of a strong

* This and the following papers are continuations of work published by us in this *Journal* some months ago under the same general title.¹ All these investigations were performed at about the same time (1918) and under the same conditions and collaboration.

¹ Haggard, H. W., and Henderson, Y., *J. Biol. Chem.*, 1919, xxxix, 163.

² Araki, T., *Z. physiol. Chem.*, 1894, xix, 422.

³ Ryffel, J. H., *J. Physiol.*, 1909-10, xxxix, p. xxix.

organic acid would at first sight appear to afford the conditions for the increased volume of breathing caused by asphyxia, and for the overbreathing and lowering of the alveolar CO_2 induced by intense muscular exertion.⁴

On the other hand, doubt should have been aroused by the fact that in non-vital chemistry it is oxidation which tends to produce acids while deoxidation usually has the contrary effect. Macleod and Knapp⁵ have found that the intravenous administration of alkali (Na_2CO_3) causes an increase of lactic acid (lactates) in the blood. This is important, for if this occurs as the result of alkalosis the appearance of lactates in the urine under the little understood conditions of asphyxia and of muscular exertion can scarcely be taken as a certain indication of acidosis. Indeed, when we examine the current conception critically and quantitatively, there appears to be very little ground for the belief that lactic acid is ever a really important factor in increase of breathing.

The chief supporter of the idea that a production of lactic acid is the cause of hyperpnea has been Haldane. About a year ago we published our dissent from this view.⁶ A reprint, which we forwarded to Dr. Haldane, reached him just as he was sending to press a paper,⁷ in which he discards his previous opinion and concurs with us in recognizing that under partial asphyxia the blood is altered, not toward acidosis, but in reality, because of overbreathing, toward alkalosis.

Indeed there seem to be signs of a drift away from the crude idea of the influence of acids in the body which has prevailed for some years, and which a too mechanical application to physiology of the physicochemical conception of the regulation of CH has for a time exacerbated rather than corrected. But a broader view is coming now. It is beginning to be recognized, for instance, that the symptoms of the so called acidosis of diabetes are due

⁴ Douglas, C. G., and Haldane, J. S., *J. Physiol.*, 1908-09, xxxviii, 420-440.

⁵ Macleod, J. J. R., and Knapp, H. J., *Am. J. Physiol.*, 1918-19, xlvii, 189.

⁶ Henderson, Y., *Science*, 1919, xlix, 431.

⁷ Haldane, J. S., Kellas, A. M., and Kennaway, E. L., *J. Physiol.*, 1919-20, liii, 181.

to the acetone derivatives as such, and not to their nature as acids. The fallacy of asphyxial acidosis is, however, deeply ingrained in current thought and will probably be removed with difficulty. Thus, nearly all the investigators who have worked recently, for instance, on the shock problem have accepted explicitly the view, stated by Bayliss,⁸ that "when the blood pressure is allowed to remain at a low level for some considerable time, there is a decrease of the bicarbonate concentration of the blood, owing to the production of some fixed acid by the tissues when inadequately supplied with oxygen." In reality, the fatal lowering of the blood alkali after hemorrhage is due, as we shall show in a later paper, to a process of an altogether different nature; namely, overbreathing similar to that produced by oxygen deficiency. The observations of Henderson, Haggard, and Coburn⁹—now in practical clinical use—have demonstrated the beneficial effects of inhalation of 6 or 8 per cent of CO₂ in air in the closely related form of surgical depression induced by prolonged and extensive major operations without hemorrhage. They find that such inhalations rapidly recall a normal alkali content to the blood, with a corresponding restoration of the circulation and other functions. If the view above quoted from Bayliss were correct, such treatment would kill instead of cure.

Inconsistency of the Present Theory.

For the sake of testing the current hypothesis of asphyxial acidosis, let us suppose that under oxygen deficiency lactic and similar acids are thrown into the blood. The results logically to be expected from their action are not at all those which experiments on partial asphyxia actually afford.¹⁰ Such an experiment has been performed many hundreds of times in the test for aviators introduced by one of us^{6, 11} into the United States Army

⁸ Bayliss, W. M., *J. Pharmacol. and Exp. Therap.*, 1920, xv, 64.

⁹ Henderson, Y., Haggard, H. W., and Coburn, R. C., *J. Am. Med. Assn.*, 1920, lxxiv, 783.

¹⁰ Henderson, Y., *Am. J. Physiol.* 1909-10, xxv, p. xii. Henderson, Y., and Scarbrough, M. M., *Am. J. Physiol.*, 1910, xxvi, 271.

¹¹ Henderson, Y., Seibert, E. G., Schneider, E. C., Whitney, J. L., Dunlap, K., Wilmer, W. H., and Berens, C., Lewis, E. R., and Paton, S., *J. Am. Med. Assn.*, 1918, lxxi, 1382-1400.

during the war. It consists in rebreathing a small volume of air (50 to 100 liters) and thus reducing its oxygen tension, while the CO_2 exhaled is absorbed by a cartridge of caustic alkali. With this and similar apparatus the careful observations of Lutz and Schneider¹² have shown that good candidates for high flying develop a progressive increase in the volume of breathing beginning even with a slight reduction (2 or 3 per cent of an atmosphere) in the tension of oxygen in the air inhaled.

On the assumption of the hypothesis that lactic acid is being produced in the bodies of these men and is escaping oxidation the following facts must be borne in mind.

1. 1 molecule of lactic acid normally burns to 3 of CO_2 .

2. Any reasonable amount of lactic acid entering the blood reacts immediately, and practically completely with NaHCO_3 . Each molecule of the acid liberates 1 molecule of CO_2 . As the amount of breathing is determined by the amount of CO_2 requiring to be exhaled, the first effect of decreased oxidation of lactic acid should be, therefore, to decrease respiration in the ratio 1:3 for whatever fraction of the lactic acid escapes combustion.

3. At the same time, however, the blood alkali is decreased, with formation of sodium lactate; and, as we have shown,¹ the volume of breathing increases in inverse proportion to the blood alkali. If, then, we calculate the percentage increase of breathing which should ultimately result from a neutralization of a part of the NaHCO_3 , and the amount of decrease of breathing which would be caused temporarily by the lessened CO_2 production in the body from non-combustion of the lactic acid, we get some such result as the following:

A reduction of blood alkali of, for instance, 10 volumes per cent involves an increase in the volume of breathing per unit mass of CO_2 eliminated of roughly 20 per cent. Thus a man who previously breathed 8 liters of air per minute would now breathe 9.6 liters. If the whole CO_2 capacity of the blood in the body is taken as 2,500 cc., a lowering of alkaline reserve from 50 volumes per cent to 40 would require enough lactic acid to liberate 500 cc. of CO_2 . Thus the CO_2 exhaled would be reduced by 1,000 cc. and the volume of air would be diminished by 25 liters (since each

¹² Lutz, B. R., and Schneider, E. C., *Am. J. Physiol.*, 1919, 1, 280.

liter of air breathed removes about 40 cc. of CO_2) before the neutralization of lactic acid and decrease of NaHCO_3 in the blood would balance the respiratory effect. Until this occurred the breathing would be markedly subnormal.

The fact is, on the contrary, that under oxygen deficiency there is an almost immediate slight increase of breathing, as Lutz and Schneider¹² have shown.

Furthermore, the theory of asphyxial acidosis requires that there should be, prior to or at least coincident with the increase of breathing, a lowering of the blood alkali as measured by its CO_2 -combining power. But this deduction likewise fails to check with the facts. For even after 60 or 90 minutes of marked oxygen deficiency the blood alkali shows only a slight fall. (A large fall would undoubtedly occur in the course of hours—that is, as acclimatization develops—but this is another matter and will be dealt with in succeeding papers.)

Immediate Effect of Diminished Oxygen on the Breathing and Blood Alkali.

In support of these statements we give the observations which follow—a line of work initiated by one of us while directing the physiological investigations at the Medical Research (Aviation) Laboratory at Mineola and continued there by Professor Schneider and Dr. Lutz, to whom we are indebted for the opportunity to quote the data here.

A sample of blood was taken, equilibrated with air containing CO_2 at 40 mm. tension, and its CO_2 -combining power determined by analysis. The subjects, healthy men, then entered a steel chamber; the air pressure was pumped down to the equivalent of an altitude of 15,000 or 18,000 feet in 15 or 18 minutes, and was maintained at this level for about $1\frac{1}{4}$ hours. Another blood sample was then taken, either shortly before or soon after the normal barometric pressure was restored. Observations were made on the volume of breathing, either by direct measurement or indirectly through analyses of the alveolar air. The data are given in Table I.

From these data it appears that deficiency of oxygen may induce a marked increase of breathing long before a perceptible

TABLE I.

Showing Effects on Healthy Men of Diminished Oxygen in Increasing Volume of Breathing before Any Considerable Lowering of Blood Alkali Occurs.

Experiment No	Time.	Barometer.	Alveolar air.		Volume of breathing.		Blood CO ₂ capacity.
			O ₂	CO ₂			
	min.	mm.	mm.	mm.	liters per min.	per cent of normal	vol. per cent
I	0	760	106	39		100	51
	18	380	41	30		130	
	92	380	38	34		115	
	98	380					48
II	0	760	105	37		100	52
	20	428	41	33		112	
	93	428	49	26		142	
	111	760	105	35		106	49
III	0	760	99	37		100	58
	19	380	42	32		115	
	73	380	36	31		119	
	99	760	98	40		92	57
IV	0	760	93	45		100	55
	18	380	63	29		155	
	53	380	47	24		187	56
	71	760	81	40		112	
V	0	760	101	43		100	49
	18	380	31	35		123	
	85	380	34	31		139	
	90	380					49
	111	760	108	35		123	
VI	0	760	99	40		100	
	48	380	31	34		118	
	89	380	33	29		138	
	112	760	97	36		111	
VII	0	760			7.2	100	61
	21	380			9.3	129	
	90	380			7.6	105	
	94	380					65

TABLE I—*Concluded.*

Experiment No.	Time.	Barometer	Alveolar air.		Volume of breathing.		Blood CO ₂ capacity.
			O ₂	CO ₂			
	<i>min.</i>	<i>mm.</i>	<i>mm</i>	<i>mm</i>	<i>liters per min</i>	<i>per cent of normal</i>	<i>vol. per cent</i>
VIII	0	760			5 5	100	57
	18	380			7.1	129	
	80	380			5 7	103	57
IX	0	760			6 2	100	61
	20	380			6 6	106	
	41	380			7.4	119	
	68	380			7 3	118	61

reduction of the blood alkali has occurred, and at first out of all proportion to the reduction. Neutralization of blood alkali by lactic acid cannot, therefore, be the causal factor in producing the initial hyperpnea of oxygen deficiency. (We shall show in the next paper¹³ that a continuation for a longer time of overbreathing and blowing off of CO₂ results in a compensatory disappearance of alkali from the blood—an adjustment which tends ultimately to restore the normal ratio of H₂CO₃:NaHCO₃. The process involved is, however, exactly the opposite of that demanded by the theory of asphyxial acidosis.)

Effects of Intravenous Injection of Lactic Acid.

The nearest experimental imitation of the assumed flooding of the circulation with lactic acid under oxygen deficiency, or during muscular work, is afforded by injecting lactic acid into the blood. We have tried this on dogs and have compared the effects with those obtained in a series of experiments, already published by us,¹ in which normal hydrochloric acid was injected, and a true and intense acidosis obtained. It will be seen that the experiments with lactic acid differ markedly from those with hydrochloric.

Protocol 1.—Dog, male, 8 kilos. Normal lactic acid (9 per cent) was administered intravenously, 5 cc. at a time, to a total of 140 cc., in the course of 3 hours. At the end of this time the animal died.

¹³ Haggard, H. W., and Henderson, Y., *J. Biol. Chem.*, 1920, xlii, 15.

10 Hemato-Respiratory Functions. III

Each injection caused a temporary increase of breathing. The respiratory volume at these times, however, never exceeded 3.0 liters of air per minute, while the normal breathing between injections averaged 2.0 liters at first and increased gradually to 2.5 liters.

Toward the end of the experiment the animal voided a red urine which showed on microscopic examination a large number of erythrocytes. Autopsy revealed the heart in diastole, the kidneys acutely inflamed, and the bladder filled with bloody urine.

Samples of blood were drawn from the femoral artery at the beginning and near the end of the experiment, were equilibrated with air containing 5.5 per cent CO_2 , and then analyzed. The CO_2 capacities thus found were as follows:

	<i>vol. per cent</i>
CO_2 before injection of lactic acid.....	45
CO_2 after " " " "	39
CO_2 decrease	6

Protocol 2.—Dog, female, 6 kilos. Normal lactic acid was injected into the jugular vein at the rate of 3 cc. per minute. The animal exhibited a moderate respiratory augmentation. It urinated profusely during the last 10 minutes of the experiment, and died quite suddenly after 32 minutes, when 90 cc. of acid had been injected. The blood was found to be very dark in color and on standing a reddish plasma separated.

The CO_2 capacity of the blood was determined as in the previous experiment, and showed:

	<i>vol per cent</i>
CO_2 before injection of lactic acid.	42
CO_2 after " " " "	39
CO_2 decrease.	3

Three points stand out in these experiments, when they are compared with those performed with hydrochloric acid.

1. It takes from two to three times as much lactic acid to kill a dog as it does, molecule for molecule, with hydrochloric acid.

2. Whereas with the smaller amounts of hydrochloric acid the blood alkali was reduced in many cases to half the normal value, the reduction induced by lactic acid was comparatively slight.

3. Animals poisoned with hydrochloric acid become truly acidotic and die in convulsions, but those killed by means of lactic acid die in quite a different manner, apparently by heart failure.

We are left with the strong impression that lactic acid, even the optically inactive form used in these experiments, is rapidly destroyed, and that the death of these animals was due to the injury to the heart and kidneys induced by the too rapid injection

of the substance. Short of such acute effects it appears from these experiments that no considerable degree of acidosis can be induced with lactic acid.

Cause of Overbreathing.

What, then, is the causal connection between deficiency of oxygen, or intense muscular exertion, and overbreathing? We suggest that in the present state of knowledge it may be appropriately denominated as respiratory x .

While it is not possible to name this important factor in breathing more exactly, the following statements may be made regarding its character and properties.

It is not a strong, fixed acid. If it has any acid property it must be extremely weak. It tends not to raise $C'H$, but through overbreathing, to lower it. The volume of breathing varies as the sum, or product, of respiratory x and $C'H$.¹⁴ (Strictly speaking, when we write $C'H$, we mean the CO_2 ratio.)

It acts, in large amounts, very much as does ethyl ether in the excitement stage of anesthesia. Its later effects resemble the disagreeable manifestations of alcoholic intoxication. But it may be quite a different type of substance from the ethereal substances thus suggested.

It is produced in active muscles, and is carried to the respiratory center in the blood.¹⁵

It is antithetic in its respiratory effects to morphine.

It may be a substance, or substances, or it may be an altered state of some blood constituent or structure; *e.g.*, the permeability of the surface of the red corpuscles to certain ions, or liberated hemoglobin.

Paradox of Anoxemic Hyperpnea.

Finally, we may here call attention to the discrepancy between theory and fact, and between two phases of present theory, in respect to the interaction of CO_2 and oxygen upon the $C'H$ of the

¹⁴ Hasselbalch, K. A., and Lundsgaard, C., *Skand. Arch. Physiol.*, 1912, xxvii, 13.

¹⁵ Geppert, J., and Zuntz, N., *Arch. ges. Physiol.*, 1888, xlii, 189.

blood on the one hand, and in respect to the influence of the CH of the blood upon the respiratory center on the other.

Several writers, Christiansen, Douglas, and Haldane, Parsons, L. J. Henderson,¹⁶ and others, hold that oxygenation of the blood increases the acid property of hemoglobin and assists in driving out CO_2 , and that deoxygenation of the blood should lower CH and lower the CO_2 tension at a uniform CO_2 content. As the respiratory center is acutely sensitive to alterations of CH , the inhalation of nearly pure nitrogen or hydrogen by lowering the CH of the blood should therefore depress respiration. In fact, however, acute oxygen deficiency for even a few seconds induces hyperpnea in most persons (*cf.* Lutz and Schneider¹²).

This paradox appears at present insoluble. To say merely that oxygen deficiency is itself a stimulus¹⁷ or that it governs the excitability of the respiratory center for CO_2 ¹⁸ leaves the question as to how it does this quite unanswered. But evidently the stimulation of breathing in this case is not due to increase of CH , for CH is altered in one sense while the activity of the respiratory center is altered in the physiologically opposite sense.

As expressed by Hasselbalch and Lungsgaard,¹⁴ the responsiveness of the respiratory center to the stimulus of CO_2 or CH varies inversely with the oxygen tension. A somewhat closer statement of these relations seems to us to be as follows: respiratory x is increased, the responsiveness of the respiratory center to CH intensified, and the breathing thereby augmented, so that the ratio $\text{H}_2\text{CO}_3 : \text{NaHCO}_3$ is reduced, whenever the ratio of the oxygen tension in the lungs (in mm.) to the alkali in use in the arterial blood (measured in volumes per cent of CO_2 capacity) is considerably reduced below the normal value. When (as after descending from a great altitude or in some phases of nephritis) the oxygen: alkali ratio is above normal, respiration is relatively depressed. Thus acidosis¹ (high ratio of $\text{H}_2\text{CO}_3 : \text{NaHCO}_3$) is induced.

¹⁶ Christiansen, J., Douglas, C. G., and Haldane, J. S., *J. Physiol.*, 1914, xlviii, 244. Parsons, T. R., *J. Physiol.*, 1919-20, liii, 42; Henderson, L. J., *J. Biol. Chem.*, 1920, xli, 401.

¹⁷ Gasser, H. S., and Loevenhart, A. S., *J. Pharmacol. and Exp. Therap.*, 1913-14, v, 239.

¹⁸ Lindhard, J., *J. Physiol.*, 1911, xlii, 337.

CONCLUSION.

The prevailing conception¹⁹ of asphyxial acidosis is in many respects diametrically opposed to the facts. Under low oxygen overbreathing occurs before the blood alkali is appreciably reduced.

Intravenous injections of lactic acid do not induce an acidosis at all commensurable with the amount administered. It is improbable that such a condition as "lactic acid acidosis" ever occurs in life. An increase of lactates in the blood or urine is probably an indication, not of acidosis, but of low ratio of H_2CO_3 : NaHCO_3 ; that is, alkalosis.

It is suggested that the stimulant produced under low oxygen be termed respiratory x . The only fact certainly demonstrable about it is that it is not a strong, fixed acid. It causes, not acidosis, but overbreathing and alkalosis.

In the next paper¹³ we shall deal with the character of the reaction which the body makes to oxygen deficiency.

¹⁹ For a general presentation of the present conception of acidosis see the discussion by Henderson, L. J., Howland, J., Woodyatt, R. T., Frothingham, C., Rowntree, L. G., Henderson, Y., and Van Slyke, D. D., *New York Med. J.*, 1916, civ, 1119.

HEMATO-RESPIRATORY FUNCTIONS.

IV. HOW OXYGEN DEFICIENCY LOWERS THE BLOOD ALKALI.

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The theory that under oxygen deficiency a production of acid occurs in the body with partial neutralization of the blood alkali has been shown in the preceding paper¹ to be no longer tenable as an explanation of anoxemic hyperpnea. It has prevailed heretofore largely because of the lack of an alternative explanation.

The problem is one which bears upon many and diverse conditions; upon diabetic and some other forms of hyperpnea, upon conditions in disease in which the oxygenation of the blood in the lungs is diminished, upon the depression of vitality and lowering of the blood alkali during and after ether anesthesia,² upon overbreathing from muscular exertion, upon acclimatization to various altitudes above sea level, and upon the ability of aviators to withstand low barometric pressures.³

As an alternative to oxygen deficiency in the causation of mountain sickness, Mosso⁴ suggested that an abnormally rapid volatilization of CO₂ out of the blood may occur under reduced barometric pressure. He termed this acapnia. The idea has in it a germ of truth, but as formulated by Mosso is quite untenable. We have recently shown, however, that the body is

¹ Haggard, H. W., and Henderson, Y., *J. Biol. Chem.*, 1920, xliii, 3. Henderson, Y., and Haggard, H. W., *J. Biol. Chem.*, 1920, xli, p. xlv.

² Henderson, Y., Haggard, H. W., and Coburn, R. C., *J. Am. Med. Assn.*, 1920, lxxiv, 783.

³ Henderson, Y., *Science*, 1919, xlix, 431.

⁴ Mosso, A., *Arch. ital. biol.* (numerous papers), 1903-05, xxxix, xli, xlii, xliii.

capable of a reaction⁵ which affords an explanation in the direction in which Mosso pointed. The whole matter turns upon the process through which the blood alkali is decreased under low oxygen.

According to the now current conception, the ionic balance of acids and bases in the blood depends upon the maintenance of a certain ratio (about 3:60) between the dissolved CO₂ and the alkali bicarbonates; or, as expressed in the well known equation

$$\text{of L. J. Henderson,}^6 \frac{\text{H}_2\text{CO}_3}{\text{NaHCO}_3} \times K = C_H. \quad (\text{We shall here assume}$$

that in this equation K , which we have termed the dissociation characteristic, is absolutely constant. If it should be shown that this factor also varies, the proportionality of C_H to the ratio H₂CO₃:NaHCO₃ will require a corresponding correction.)

The respiration of a healthy man ordinarily maintains in the blood a certain definite value of C_H which is probably almost the same⁷ when he is acclimatized to sea level or to an altitude of 5,000 or 10,000 or perhaps even 15,000 feet above sea level. At these altitudes, however, he breathes quite different volumes of air per unit mass of CO₂ eliminated. Thus, as was shown by the Pike's Peak expedition,⁸ a man maintains tensions of about 39 mm. of CO₂ in the alveolar air at sea level and only 26 mm. at 14,000 feet, for evidently the more air he breathes the more the CO₂ in the lungs is diluted. As the H₂CO₃ of the blood is determined through direct physical action by the tension of CO₂, it follows that in all conditions of equilibrium, that is in complete acclimatization to any altitude, the volume of air breathed must be adjusted to an inverse proportion with the amount of alkali in use in the arterial blood. In this way only can the ratio H₂CO₃:NaHCO₃ be maintained alike when the figures are 3:60, or 4:80, or 2:40, or any intermediate values—all of which give the normal ratio of 5 per cent; i.e., dissolved CO₂:combined CO₂ :: 3:60 :: 5:100. Evidently this ratio may be normal at nearly any amount of blood alkali, and it may be altered or

⁵ Henderson, Y., and Haggard, H. W., *J. Biol. Chem.*, 1918, xxxiii, 333, 345, 355, 365.

⁶ Henderson, L. J., *Ergebn. Physiol.*, 1909, viii, 254.

⁷ Hasselbalch, K. A., and Lindhard, J., *Biochem. Z.*, 1915, lxviii, 265, 295.

⁸ Douglas, C. G., Haldane, J. S., Henderson, Y., and Schneider, E. C., *Phil. Tr. Roy. Soc. London, Series B*, 1912, ccii, 302.

restored by change in either member of the ratio. In the body, as we shall have occasion to show, either member follows the other back toward the normal relation.

(We suggest that the term CO_2 ratio be used to replace " H_2CO_3 : NaHCO_3 ," "ratio of dissolved CO_2 to combined CO_2 ," and "relation, proportionality, or ratio of alveolar CO_2 tension to alkaline reserve," and that it be expressed as a percentage, as above.)

Evidently if acid is added to the blood, or alkali withdrawn, there will be two forms of augmentation of breathing: first, a temporary augmentation to remove the excess of CO_2 liberated; and second, the maintenance of the larger volume of breathing necessary to keep the tension of CO_2 in the lung air at the lower value to correspond to the diminished blood alkali, and keep the CO_2 ratio normal. Such diminution of alkali and its consequences may be termed the acidotic process. It involves, during its development, a high CO_2 ratio. We have not denied that such a process occurs. We have ourselves shown that increase of breathing may be induced by intravenous injection of acid. Our point is merely that under low oxygen or muscular exertion, and probably under other conditions, the overbreathing is so great that the CO_2 ratio is reduced below normal, and the C_H of the blood varies toward the alkaline, instead of the acid, side of neutrality.

In contrast to the acidotic process the body is endowed, as we have shown,⁵ with the capacity to bring the CO_2 ratio (*i.e.*, H_2CO_3 : NaHCO_3) back to normal in another way, as follows: whenever respiration is excited to such activity that the H_2CO_3 of the blood is reduced below its normal relation to the alkali, a compensatory fall of NaHCO_3 follows, either through a passage of alkali out of the blood into the urine and tissues, or by immobilization within the blood itself, or through some equivalent readjustment. This is the acapnial process—the reaction to an alkalosis due to a relative deficiency of CO_2 .

Both the acidotic and the acapnial processes result in a lowered alkali, but otherwise they are fundamentally different both in their intermediate and their terminal states. During the acidotic process the CO_2 ratio is above normal and there is therefore a high C_H , or acidosis. During the acapnial process on the other hand, the CO_2 ratio (H_2CO_3 : NaHCO_3) is below normal. There

is a low C_H and a state of alkalosis. Both result in hypocapnia or low alkali carbonate in the blood.

Differentiation of the Acidotic and the Acapnial Processes.

In attempting to decide which of these conditions occurs as the result of deficiency of oxygen two facts regarding the influence of the oxygen supply upon the volume of breathing must be kept in mind: (a) decrease of oxygen tension, even slight, induces temporarily⁹ overbreathing and blowing off of CO_2 ; and (b) the readjustment to decreased oxygen tension, or acclimatization to altitude, involves (as was shown by the Pike's Peak expedition⁸) a maintained increase of breathing and a normally lower tension of CO_2 in the air of the lungs—26 mm. in contrast to 39 mm. at sea level.

From gross appearances these phenomena could be, and until the present time have been, explained as due to the acidotic mechanism. We propose here to show that, on the contrary, deficiency of oxygen and its product, the stimulant "respiratory x ,"¹ act, not through a neutralization of blood alkali, but through overbreathing, alkalosis, and the acapnial process.

To this end we shall make use in presenting our experiments of the CO_2 diagram used in our earlier work on the effects of intravenous injection of hydrochloric acid.¹⁰ The full force of the evidence can be seen only by comparing the two sets of experiments, those with hydrochloric acid and those under low oxygen. The gist of the matter is as follows:

In the CO_2 diagram one coordinate expresses the tension of CO_2 in the air in the lungs and in the arterial blood, while the other shows the alkali in use and the CO_2 -combining power of the blood. A diagonal line, the OC line, in which all points have the same ratio of abscissa : ordinate, indicates therefore the normal ratio of $H_2CO_3 : NaHCO_3$; *i.e.*, the CO_2 ratio and (presumably) the C_H . The CO_2 dissociation curve of the blood is plotted from analyses of the blood at tensions of 18, 40, and 72 mm. at body temperature. The position at which the arterial blood comes on

⁹ Lutz, B. R., and Schneider, E. C., *Am. J. Physiol.*, 1919, 1, 280.

¹⁰ Haggard, H. W., and Henderson, Y., *J. Biol. Chem.*, 1919, xxxix, 163.

this curve is found either by analyses of the CO_2 content of the blood, or of the CO_2 tension of the pulmonary air.

If then the arterial point falls to the right of the *OC* line there is an abnormally high CO_2 ratio ($\text{H}_2\text{CO}_3 > \text{NaHCO}_3$), high CH , and acidosis. But if it falls to the left of the line it indicates overbreathing, lowered CO_2 ratio, reduced CH , and, in other words, alkalosis.

It will be seen in the experiments reported here that it is the latter condition which occurs under low oxygen, and that in the course of hours the CO_2 dissociation curve, that is the blood alkali, falls lower and lower, indicating the compensatory passage of alkali out of the blood. Thus the point *A*, indicating the arterial blood, descends to the left of the *OC* line. This contrasts sharply with the process seen in our previous experiments under injection of hydrochloric acid in which *A* descended to the right of the *OC* line. It is noteworthy, however, that in the return from low oxygen to atmospheric air (in Experiments 2 and 3) respiration is depressed—not perhaps absolutely, but relatively to the blood alkali. Thus during recovery the CO_2 ratio rises above normal, the arterial point swings to the right of the *OC* line, and the rise of the dissociation curve indicates that the result of this acidosis is to recall alkali to the blood.

EXPERIMENTAL.

Our experiments were performed upon dogs. They received no general anesthetic, but were handled gently and firmly, so that no disturbance of respiration, a sure sign of physical or mental discomfort, occurred. Blood samples were obtained from the femoral artery, exposed under cocaine.

The essential experimental condition was that of rebreathing the air in a large spirometer through alkali. The animals thus gradually consumed the oxygen of the air, and developed anoxemia. This also involves no discomfort, as we know from extensive experience on men, even when the asphyxia is pushed to the point of unconsciousness.

A conical mask of sheet zinc was fitted over the head up to the eyes and made tight with adhesive plaster with the greatest care to prevent leaks. It was connected with as little dead space as

possible to inspiratory and expiratory valves. Through one of these valves the animal inhaled from a spirometer of 200 liters capacity; through the other the expired air passed by way of a cartridge containing 2 liters of finely shaved NaOH back into the spirometer. The air in the spirometer was analyzed for its oxygen content and to insure the absence of more than a trace of CO_2 .

A gas meter of low resistance could be inserted temporarily in the circuit; and the volume of breathing was thus measured at intervals.

In one experiment the gaseous conditions of the interior of the body were followed by means of the "abdominal air method."¹¹ 2 liters of a gas mixture of 7 per cent oxygen and 93 per cent nitrogen were introduced into the peritoneal cavity before the beginning of the experiment and samples were withdrawn and analyzed at intervals.

Experiment 1.—Dog, female, 7.5 kilos. Rebreathed from spirometer containing 200 liters of air beginning at 12 m. Progressive decrease of oxygen tension in the inspired air until death, 7 hours later. Columns 4, 5, and 6 show the data from which the CO_2 dissociation curves, numbered as in Column 1, are plotted in Fig. 1. Column 8 shows the H_2CO_3 in the arterial blood, and Column 9 the NaHCO_3 in use. Column 10 gives the CO_2 ratio ($\text{H}_2\text{CO}_3:\text{NaHCO}_3$) and Column 11 the C_{H^+} calculated from this ratio. The abdominal air and volume of respiration were determined as described in the text.

Curve No	Time.	Oxygen tension.	Blood equilibrated with CO_2 at			Arterial blood.			CO_2 ratio.	C_{H^+} (Char 8).	Abdominal air.		Volume of respiration
			18 mm.	40 mm.	72 mm.	CO_2 content	CO_2 dissolved.	CO_2 combined.			O_2	CO_2	
		mm.	vol. per cent	vol. per cent	vol. per cent	vol. per cent	vol. per cent	vol. per cent	per cent		mm	mm	liters per min.
1	11.50 a.m.	145	29	44	54	44	2 70	41 30	6 54	0 523	56	40	3 1
2	1.55 p.m.	118	29	44	55	44	2 70	41 30	6 54	0 523	54	40	3.1
3	5.40 "	55	29	42	51	40	2 40	37 60	6 39	0 511	38	36	4.4
4	6.20 "	30	22	36	45	26	1 37	24 63	6.10	0 498		20	10.1
5	7.00 "	22	21	33	42	21	1 14	18 86	6.04	0 483	30	17	12.0
6	7.20 "	21	17	23	29	14	0 74	13.26	5.59	0 446			
	7.22 "	Death.											

¹¹ Haggard, H. W., and Henderson, Y., *J. Biol. Chem.*, 1919, xxxviii, 71.

Note that the increase of breathing and lowering of arterial CO_2 content exceed the degree of reduction of alkali, as indicated by the combined CO_2 , and that the CO_2 ratio and C_H are therefore lowered. The causal sequence evidently is (1) lowering of oxygen tension, (2) an increased production of respiratory x , (3) excessive respiration and a blowing off of CO_2 , (4) decrease of the CO_2 ratio and lowering of C_H , that is alkalosis, and (5) the compensatory disappearance of alkali from the blood.

Experiment 2.—Dog, male, 12 kilos. Breathed an atmosphere of progressively decreasing oxygen tension from 12 to 5.44 p.m.; thereafter normal air.

Curve No	Time.	Oxygen tension.	Blood equilibrated with CO_2 at			Arterial blood.			CO_2 ratio.	C_H^7 (Char. S).
			18 mm.	40 mm.	72 mm.	CO_2 content.	CO_2 dissolved.	CO_2 combined.		
		mm	vol per cent	vol per cent	vol. per cent	vol. per cent	vol. per cent	vol. per cent	per cent	
1	11.45 a.m.	155	38	49	60	51	2.96	48.04	6.18	0.493
2	3.55 p.m.	70	30	44	55	38	2.08	35.96	5.78	0.462
3	5.30 "	30	27	38	47	29	1.48	27.52	5.38	0.430
4	6.35 "	155	32	44	55	44	2.70	41.30	6.54	0.523

Note that the development of alkalosis, lowered CO_2 ratio, and lowered C_H in Columns 10 and 11 is due to overbreathing. This is indicated by the fact that the arterial CO_2 content is reduced much more rapidly than the CO_2 capacity. Note that in Columns 4, 5, and 6 the blood alkali or CO_2 -combining power falls, but this fall is much slower than that of the arterial CO_2 content. Note that after restoration to the normal air the ratio $\text{H}_2\text{CO}_3 : \text{NaHCO}_3$ (Column 10) and the C_H rise above normal (due to depressed breathing), and alkali is gradually recalled to the blood. Figures in Column 1 refer to the curves plotted in Fig. 2.

Experiment 3.—Dog, male, 12.4 kilos. Rebreathed an atmosphere of progressively decreasing oxygen tension from 12 to 4.10 p.m.; thereafter normal air. At 4.10 p.m. the animal was unconscious and apparently

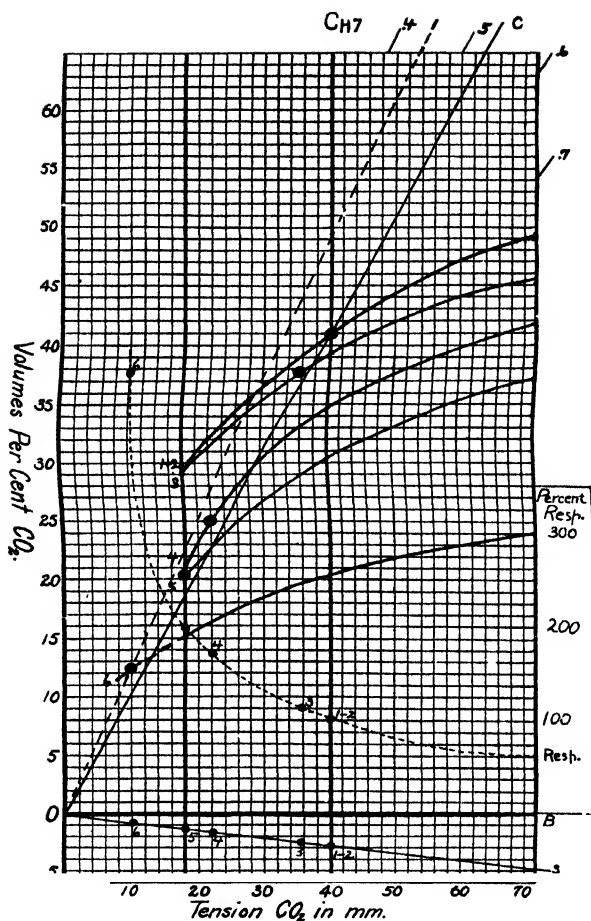


FIG. 1. The CO₂ diagram of the blood of a dog under progressively lower tensions of oxygen. From the data of Experiment 1.

OS shows the CO₂ dissolved at all tensions of CO₂. It is positive, not negative. The CO₂ dissociation curves 1 to 6 are plotted from analyses of the blood equilibrated to tensions of 40, 72, and 18 mm. (in this order) at body temperature. The dots indicate the arterial blood. The OC line shows the normal CO₂ ratio and (presumably) the C_H of the blood. Deviation of the arterial point to the left of the OC line indicates overbreathing, low alveolar and arterial CO₂ tension, and consequent alkalosis. The progressive lowering of the CO₂ dissociation curve expresses the disappearance of alkali from the blood in the attempt of the organism to compensate the alkalosis.

The full significance of these relations can be seen only when they are compared with those in the CO₂ diagrams of acidosis from injections of HCl previously published.¹⁰ In the latter the arterial points deviate to the right of the OC line.

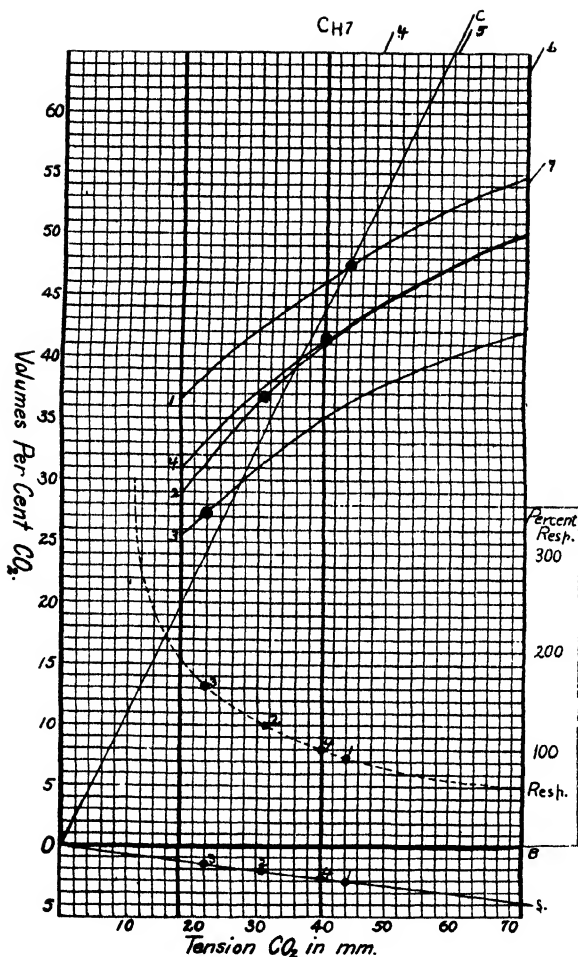


FIG. 2. The CO_2 diagram of the blood under progressively lower tensions of oxygen, Curves 1, 2, and 3; and during recovery when breathing normal air again, Curve 4. From the data of Experiment 2.

Note that under oxygen deficiency the arterial point deviates to the left of the OC line, indicating overbreathing and a consequent alkalosis. The compensatory disappearance of alkali from the blood is shown by the progressive lowering of the dissociation curve. Note that on restoration to normal oxygen tension, with the consequent abnormally high ratio oxygen:alkali, the respiration is relatively depressed and the arterial point swings to the right of the OC line, thus inducing a condition of acidosis ($H_2CO_3 > NaHCO_3$). Under such conditions it is here seen that alkali is recalled to the blood and the dissociation curve rises.

dying, and required artificial respiration for a few minutes, under which it recovered.

Curve No.	Time.	Oxygen tension.	Blood equilibrated with CO ₂ at			Arterial blood.			CO ₂ ratio.	C _H ⁷ (Char. 8).
			18 mm	40 mm	72 mm.	CO ₂ content.	CO ₂ dissolved.	CO ₂ combined.		
		mm.	vol. per cent	vol. per cent	vol. per cent	vol. per cent	vol. per cent	vol. per cent	per cent	
1	11.50 a.m.	155	36	49	61	50	2 96	47 04	6 30	0 504
2	2.14 p.m.	92	32	42	53	39	2 02	36 98	5 47	0.437
3	4 10 "	35	27	36	45	27	1.28	25 72	4 97	0 398
4	4.45 "	155	32	47	59	46	2 76	43 24	6 38	0 510

Note that the fall of arterial CO₂ content indicates marked overbreathing which induces a lowered CO₂ ratio and C_H, and is followed by a diminution of blood alkali, as indicated by the CO₂-combining power (Columns 4, 5, and 6). Note also that, after restoration to the normal oxygen tension respiration is depressed below the amount needed for the normal C_H, the CO₂ ratio rises above normal (Column 10), and alkali is recalled to the blood (Columns 4, 5, and 6). The CO₂ diagram which may be plotted from these data is practically identical with Fig. 2.

Overbreathing, Alkalosis, and Hypocapnia.

These experiments afford a striking contrast to those in the first paper of this series.¹⁰ There hydrochloric acid was injected into the blood and the alkali was thus neutralized with a consequent increase of the CO₂ ratio (H₂CO₃ : NaHCO₃) and of C_H, and an increase of breathing to remove the excess of CO₂. Here, on the contrary, low oxygen (through the agency of respiratory *x* which, whatever it is, is evidently not a strong acid) causes first overbreathing and blowing off of CO₂—thus markedly reducing the CO₂ ratio (Column 10) and the C_H. In compensation alkali gradually passes out of the blood and its CO₂-combining power (Columns 4, 5, and 6) gradually falls. In the former experiments with acid the lowering of the blood alkali, hypocapnia, was the first event in the series. Here it is the last.

In Experiments 2 and 3 when a normal oxygen tension was restored the recovery involved the development of a high CO_2 ratio and a supernormal Cl^- ; that is, acidosis. This phenomenon occurred during recovery from injection of hydrochloric acid in the previous series of experiments also,¹⁰ and seems to us to be a point of great theoretical interest in its suggestion as to the process through which the blood alkali and respiration become adjusted to the oxygen tension prevailing at the altitude at which the man or animal lives.

Apparently the stimulant, respiratory x , whatever its character, is not merely the result of reduced oxygen, but rather the resultant of the oxygen and the alkali. Whenever the ratio oxygen:alkali is below normal the amount of respiratory x is increased. Overbreathing occurs, CO_2 is blown off, and the CO_2 ratio falls below normal ($\text{H}_2\text{CO}_3 < \text{NaHCO}_3$). The alkali passes out of the blood until the ratio oxygen:alkali and the ratio $\text{H}_2\text{CO}_3 : \text{NaHCO}_3$ are both normal again. Thus the three principal respiratory factors, pulmonary oxygen tension, alveolar CO_2 , and the CO_2 -combining power of the blood, are all diminished finally in the same proportion of their sea level values, and equilibrium is thus reattained at a new level. Furthermore the process of seeking equilibrium between these three factors is seen in Experiments 2 and 3 to work equally well for increase of oxygen tension. There is a depression of respiration, a rise of the CO_2 ratio ($\text{H}_2\text{CO}_3 > \text{NaHCO}_3$), a temporary acidosis, and a recall of alkali to the blood.^{5,10} Evidently the oxygen tension in the lungs and arterial blood is the fundamental factor controlling the breathing, the alveolar and arterial CO_2 tension, *i.e.* the pulmonary dilution of the CO_2 with air, and the blood alkali. (A more precise statement of the quantitative relations involved in these adjustments will be given in the succeeding paper.)¹²

One or two additional points deserve mention here. We have shown in the first paper of this series¹⁰ that after the blood alkali has been diminished by administration of hydrochloric acid the inhalation of moderate percentages of CO_2 in air—such as do a normal animal no harm whatever—rapidly proves fatal. On the other hand, we have found, both by experiments upon animals

¹² Haggard, H. W., and Henderson, Y., *J. Biol. Chem.*, 1920, xliii, 29.

and by observations upon men after prolonged and extensive major operations in which the blood alkali has been diminished by overbreathing and subnormal metabolism, that inhalations of CO_2 are markedly beneficial and rapidly recall a normal content of alkali to the blood.²

The reactions, beneficial or harmful, to inhalations of CO_2 afford, therefore, an effective method of determining whether a low blood alkali, *i.e.* hypocapnia, has been induced through the acidotic or the acapnial process. Judged by this test recent experiments of Hasselbalch and Lindhard⁷ and earlier observations of Mosso⁴ indicate that the decrease of blood alkali under low oxygen is of the acapnial and not of the acidotic variety. After exposure to low oxygen for several hours they experienced markedly unpleasant symptoms, *i.e.* mountain sickness, and these effects were distinctly reduced by inhalations of CO_2 in proper dilution. We do not consider, however, that these observations support the claim of Mosso and his followers that CO_2 inhalation during oxygen deficiency is advantageous. In fact we have found that dogs to which CO_2 was administered, even in moderate percentage, during low oxygen experiments, such as those above detailed, were stimulated to violent respiration, and in some cases died suddenly from heart failure.

Apparently the nausea and other discomfort after violent physical exertion are also in part at least due to overbreathing.¹³ In experiments with different types of facpiece in gas masks during the war (carried out for the Chemical Warfare Service), we made observations upon a number of university athletes who were accustomed to consistent performance on the running track. The tests consisted in running the half mile and mile against the watch with a pace maker, while the subject was wearing the different types of mask. Without exception the men noticed and voluntarily reported that discomfort after the test was lessened by masks having a moderate dead space. This space was sufficient to decrease somewhat the loss of CO_2 during overbreathing, but not sufficient appreciably to diminish the intake of oxygen.

¹³ Collip, J. B., and Backus, P. L., *Am. J. Physiol.*, 1920, li, 568. Campbell, J. M. H., Douglas, C. G., and Hobson, F. G., *Phil. Tr. Roy. Soc. London, Series B*, 1920, ccx, 1.

CONCLUSION.

The process through which oxygen deficiency lowers the blood alkali is as follows: overbreathing blows off an excess of CO_2 (acapnia), leaving the CO_2 ratio, *i.e.* the relation of H_2CO_3 to NaHCO_3 , and therefore presumably the C_H in the blood, below normal. This alkalosis¹⁴ is then compensated by a disappearance of alkali from the blood.

On restoration to normal oxygen tension the reverse process occurs: the breathing is relatively depressed, the CO_2 ratio (H_2CO_3 : NaHCO_3) and the C_H of the blood are raised above normal, and this acidosis recalls alkali to the blood.

¹⁴ Haldane, J. S., Kellas, A. M., and Kennaway, E. L., *J. Physiol.*, 1919, liii, 181.

HEMATO-RESPIRATORY FUNCTIONS.

V. RELATION OF OXYGEN TENSION AND BLOOD ALKALI IN ACCLIMATIZATION TO ALTITUDE.

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In the previous paper¹ we have presented evidence which indicates that the tension of oxygen is the fundamental condition to which the organism, slowly but surely, adjusts its respiratory activity, its alveolar tension of CO_2 , and the amount of H_2CO_3 in the arterial blood. It thus becomes highly probable also that the tension of oxygen to which a normal man or animal is acclimated determines the amount of blood alkali. Theory demands this, for otherwise the CO_2 ratio ($\text{H}_2\text{CO}_3:\text{NaHCO}_3$) would not be the same in inhabitants of all altitudes, and the Cl_H of the blood would be different in a man living, for instance, in New York, Denver, or at the summit of Pike's Peak. The investigations of Hasselbalch and Lindhard² indicate that with complete acclimatization the Cl_H of the blood is the same at all altitudes.

In the first paper of this series³ we attempted to formulate more precisely than hitherto the laws of respiration. The third law, there stated and here to be discussed, is an attempt to define the balance which the various factors in breathing tend to approximate. It is: In physiological equilibrium at all barometric pressures, that is in acclimatization at all altitudes, the tension of CO_2 and amount of alkali in use in the arterial blood vary in direct proportion to the alveolar tension of oxygen, while the volume of true breathing, *i.e.* alveolar ventilation, is inversely proportional.

¹ Haggard, H. W., and Henderson, Y., *J. Biol. Chem.*, 1920, xliii, 15.

² Hasselbalch, K. A., and Lindhard, J., *Biochem. Z.*, 1915, lxxviii, 265, 295.

³ Haggard, H. W., and Henderson, Y., *J. Biol. Chem.*, 1919, xxxix, 163.

According to this law the general relations under which the C_H of the blood should be constant in a normal individual fully acclimatized, that is in hemato-respiratory equilibrium, at any altitude and barometric pressure may be expressed as follows:

$$(\text{Bar} - T_{H_2O}) \times F_{RQ} = T_{O_2} = T_{CO_2} \times C_1 = Q_{CO_2} \times C_2$$

$$= \frac{1}{100 \left(\frac{760 - T_{H_2O}}{\text{Bar.} - T_{H_2O}} \right) \text{Resp.}}$$

In this formula Bar. is the mean atmospheric pressure of the altitude. T_{H_2O} is the tension of water vapor in the lungs at body temperature, 47 mm. at 38°C . F_{RQ} is a factor for the percentage of oxygen in the dry gases of the lungs, with a value usually about 0.14, depending upon the alveolar respiratory quotient. T_{O_2} and T_{CO_2} are the pulmonary tensions of oxygen and CO_2 . Q_{CO_2} is the amount of alkali, expressed in volumes per cent of CO_2 , called into use in the arterial blood. In the CO_2 diagram it is the ordinate of the point of intersection of the CO_2 dissociation curve and the OC line. C_1 and C_2 are constants for the individual, the value of C_1 being about 2.5, and that of C_2 , less accurately known and probably subject to wider variations, lying usually between 1.9 and 2.5. 100 Resp. is the volume of true breathing, *i.e.* alveolar ventilation, per 5.5 cc. of CO_2 eliminated at sea level. The denominator of the fraction solves to the relative volume of true breathing at the altitude.

These relations are expressed graphically in Fig. 1.

An extensive series of observations has been made by FitzGerald⁴ bearing upon the relations between the mean barometric pressure of any altitude and the alveolar tensions of oxygen and CO_2 of its inhabitants. It covers elevations from sea level up to 11,000 feet; and data from the Pike's Peak expedition⁵ extend the series up to 14,000 feet. Her extremely careful technique gives these observations great value. In most of this series, however, no subject, except the investigator herself, could be tested in acclimatization to more than one altitude; and averages

⁴ FitzGerald, M. P., *Phil. Tr. Soc. London, Series B*, 1913, cciii, 351; *Proc. Roy. Soc. London, Series B*, 1914-15, lxxxviii, 248.

⁵ Douglas, C. G., Haldane, J. S., Henderson, Y., and Schneider, E. C., *Phil. Tr. Roy. Soc. London, Series B*, 1912, ccii, 302.

of inhabitants of Georgia for one group of levels, and of Colorado for another may fairly be expected, considering differences of climate, diet, and other conditions, to show some variations from a purely barometric basis. Even so, all things considered, the diagram which FitzGerald gives to express the relation of alveolar oxygen and CO_2 tensions to the barometer is so near to simple linear proportions that it was from these data that we were led to attempt to formulate the law.

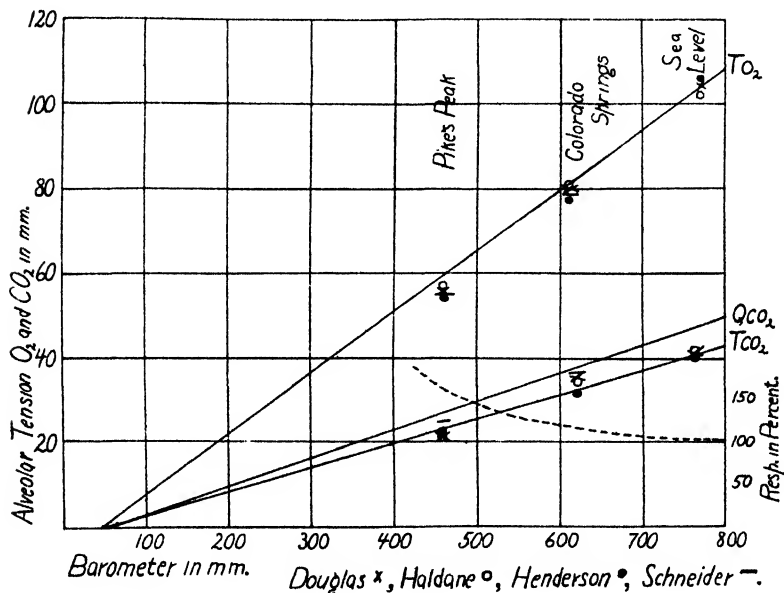


FIG. 1. The relations of the alveolar and arterial oxygen and CO_2 tensions (T_{O_2} and T_{CO_2}), the amount of blood alkali (Q_{CO_2}), and the volume of (true) breathing requisite to full acclimatization to any barometric pressure.

Fortunately, observations upon members of the Pike's Peak expedition⁵ afford exactly the data needed. The subjects were approximately acclimated successively at sea level, 14,000, and 6 000 feet. In Fig. 1, the lines T_{O_2} and T_{CO_2} express the requirements of exact proportionality to the barometric pressure minus the water vapor tension of the alveolar air. The points falling on or near these lines show the results of pulmonary air analyses

at sea level and the conditions most nearly approaching acclimatization, that is, after the longest stay for each man, at Colorado Springs and on the summit of Pike's Peak.

It is probable that even in these observations acclimatization was not quite complete, and that the alveolar tensions of CO_2 were therefore a little higher and the tensions of oxygen a little lower than would be the case in complete acclimatization. This is particularly true in Schneider who, as a variation on the conditions of the other members of the expedition, descended twice during the period of investigation. The greater deviation from theory in his case bears out the idea that acclimatization was slightly incomplete in the others also.

At the time the report of the Pike's Peak expedition was written the theory of formation of lactic acid and adjustment of respiration through the acidotic process was apparently the only available explanation of the respiratory readjustments to altitude. Previous papers of this series, in general agreement with the opinion reached independently by Haldane,⁶ indicate clearly that the adjustment is through alkalosis and the acapnial process.

The evidence in the literature bearing upon the amount of blood alkali (Q_{CO_2} in Fig. 1) at altitudes is at present less complete and direct than that for the tension of CO_2 but in the main it is clear and decisive. It is contained chiefly in the reports of the Mt. Rosa⁷ and Pike's Peak expeditions of 1911 and the more recent work of Hasselbalch and Lindhard.² Both of the earlier groups of investigators used the Barcroft method and found the blood alkali to be decreased to such an extent that when a sample of blood was equilibrated with the subject's alveolar air the hemoglobin was approximately mesectic—indicating a normal CH with a decrease of blood alkali proportional to the decrease of CO_2 tension and inversely proportional therefore to the volume of true breathing.

The relations of hemato-respiratory equilibrium to the barometer, as defined in the law above given and illustrated in Fig. 1, are thus seen to be the limits which the three main factors in

⁶ Haldane, J. S., Kellas, A. M., and Kennaway, E. L., *J. Physiol.*, 1919, liii, 181.

⁷ Barcroft, J., Camis, M., Mathison, C. G., Roberts, F., and Ryffel, J. H., *Phil. Tr. Roy. Soc. London, Series B*, 1914, ccvi, 49.

respiration, *viz.* the tension of oxygen, the H_2CO_3 , and the NaHCO_3 in the blood, gradually approach as acclimatization develops. As the experiments in the previous paper show, overbreathing, alkalosis, and the consequent lowering of the blood alkali are the steps through which the changes are effected on passing from a lower to a higher altitude. Slight depression of breathing, high CO_2 ratio ($\text{H}_2\text{CO}_3 : \text{NaHCO}_3$), acidosis, and recall of alkali to the blood are the stages in readjustment on return to sea level.

It must be kept in mind, however, that these readjustments are matters of days or weeks. For the aviator who is at a great altitude for only an hour or two the capacity to develop respiratory x , overbreathing, and a low CO_2 ratio seems of the greatest importance.^{6,8} The alkalosis tends to shift the affinity of hemoglobin for oxygen and thus assists absorption.

Finally, we may here point out the bearing of these relations upon the nature of that factor in breathing which we call respiratory x . We use this term as an alias for the state of the blood, formerly assigned erroneously to the increase of lactic acid, through which alterations of oxygen tension bring about their effects upon the respiratory center. From the relations above shown it appears that the amount of this respiratory stimulant may be subnormal, thus inducing acidosis, as well as supernormal, and that it is dependent not upon the oxygen tension alone, but upon the ratio of the oxygen (T_{O_2}) to the blood alkali (Q_{CO_2}).

If this view is correct it affords an indication as to the line along which we must look for further information regarding this extremely important factor in breathing, in the maintenance of the normal ionic equilibrium of the blood, and in the causation of acidosis when the blood alkali is lowered in disease.³

CONCLUSION.

The barometric pressure to which one becomes acclimatized, through the tension of oxygen, is the fundamental factor controlling the volume of air breathed per unit mass of CO_2 eliminated, the alveolar CO_2 tension, and the amount of alkali called into use in the blood. The law of these relations is here formulated, and its bearing upon the unknown anoxic respiratory stimulant and hyperoxemic respiratory depressant is indicated.

⁸ Henderson, Y., *Science*, 1919, xlix, 431.

METHOD FOR DETERMINATION OF CALCIUM IN SMALL QUANTITIES OF BLOOD SERUM.

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In 1916 Marriott, Howland, and Haessler (1) described a micro method for the quantitative estimation of calcium in blood serum. The final determination in their method depends on the property which oxalic acid possesses of decolorizing a solution of ferric thiocyanate. It was not maintained that this method possesses the degree of accuracy expected of a volumetric or gravimetric procedure, but that it is sufficiently accurate to demonstrate such changes in the concentration of calcium in serum as are of clinical significance. In commenting upon their method the authors state (2): "The method is time-consuming and requires a considerable degree of experience in the various manipulations and in the final readings." To remedy these defects the method described below was devised.

Since the work was begun several new methods have appeared in the literature. The procedure described by Halverson and Bergeim (3) requires at least 10 cc. of blood for a single determination and obviously cannot conveniently be used for studies on infants and children. Jansen's (4) method also requires 10 cc. of blood. The introduction of a separate procedure for the preliminary removal of phosphates, as is done in this method and in that of Dienes (5), complicates matters unnecessarily and increases the possibility of error.

The nephelometric method of Lyman (6) has probably been more extensively used in this country for the estimation of calcium in small quantities of blood than any other method. Denis and Minot (7) have reported determinations on the calcium content of the plasma of five normal adult males and one female. They used Lyman's method and found 7.6 to 11.9 mg. of calcium

per 100 cc. of plasma. We have found the concentration of calcium in the serum of normal adults to be singularly constant and hence look upon such striking variations as indicating either that the supposed normal adults were not normal or that the method itself is at fault. Lyman has reported no studies on artificial blood salt solutions, and has made no attempt to recover known quantities of calcium added to serum.

After our method had been completed and in actual use for several months, our attention was called to a method described by de Waard. In his method (8) calcium is precipitated as the oxalate by adding 0.5 cc. of saturated ammonium oxalate, then enough concentrated ammonia until the solution smells ammoniacal on shaking, and finally enough glacial acetic acid until it smells acid. De Waard reports analyses of solutions of blood salts. Each sample contained calcium in amount equal to that found in 4 cc. of serum, or about 8 cc. of blood. No analyses of normal human serum or whole blood are given. No attempt to recover calcium added to blood is reported. It is stated that cow serum contains 8.4 to 8.6 mg. of calcium per 100 cc. of serum. This is in rather striking contrast with a series of determinations reported by Halverson and Bergeim (3). The latter authors never found less than 10 mg. of calcium per 100 cc. of cow serum. It might be pointed out that de Waard's method of precipitation is open to the objections raised by Richards and collaborators (9) and McCrudden (10).

Principle of the New Method.

The blood serum is ashed by the method of Stolte (11) or in the usual manner. The calcium is precipitated by a procedure which in principle is identical with that of McCrudden. A definite amount of 0.1 N oxalic acid in 0.05 N sulfuric acid equal to about four times the equivalent of calcium present is added. The final volume is made up to 2 cc. and an aliquot of the filtrate is titrated with 0.01 N potassium permanganate.

The Method.

1 or 2 cc. of serum or plasma are measured into a platinum crucible, evaporated to dryness on the water bath, and dehydration is completed in the oven at 110°C. The crucible is then

placed in a quartz dish over a Meker or Fisher burner. It is heated gently at first and then more vigorously. The outer dish is then covered with a quartz plate and the heating continued until ashing is complete. The platinum crucible is then removed and the ash dissolved in a small quantity of 1.0 N HCl. It is again evaporated to dryness and ashed as before. A crystalline material is obtained which is readily soluble in not more than 1 cc. of 0.1 N H_2SO_4 .¹ The solution is transferred to a Pyrex tube 100 mm. in length and 10 mm. in diameter calibrated for 1 and 2 cc. The tube is heated for a few minutes in the water bath and a drop of 0.01 N potassium permanganate is added to prove the absence of any oxidizable material. The pink color should persist for at least 1 minute. One drop of 0.01 per cent phenol-sulfonephthalein is added followed by one drop of concentrated ammonia. The tube is then heated on the water bath to drive off the excess of ammonia. At this point a fluffy precipitate forms. To the tube while hot is added exactly 0.3 cc. of 0.1 N oxalic acid in 0.05 N sulfuric acid. This is added in three portions with shaking after each 0.1 cc. The fluffy precipitate dissolves and is replaced by a copious fine crystalline precipitate. The reaction is usually acid at this point. If it is not, sufficient 0.1 N sulfuric acid is added until the color is lemon-yellow which corresponds to a pH of 6.4 to 6.6. Heating is then continued for a few minutes. The tube is then cooled and 0.1 cc. of a saturated solution of sodium acetate is added and the tube well shaken. The volume is made up to 2.0 cc. and the tube allowed to stand several hours or over night. The material is then filtered through hardened filter paper. 1 cc. of the filtrate is measured into a small beaker. To this, 1 cc. of 20 per cent sulfuric acid (20 cc. of concentrated acid diluted to 100) is added.² The beaker is heated on the water bath for a few minutes and then titrated *in good daylight* to a definite pink that persists for

¹ About 0.5 cc. of 0.1 N sulfuric acid is added and solution of the ash facilitated by warming over the steam bath. The solution is then transferred with a small pipette to the Pyrex tube and the process repeated by using two additional portions of 0.25 cc. of 0.01 N sulfuric acid. We have repeatedly demonstrated that transfer of calcium is complete.

² Hydrochloric acid should be avoided as it is oxidized to free chlorine by permanganate.

at least 30 seconds. For very accurate work the end-point is determined by comparison with an equal volume of water in a beaker of the same size. The amount of permanganate necessary to give the same intensity of color with an equal volume of water is also determined and this volume is subtracted from the titration. A blank determination should also be made on the reagents. For most purposes the subtraction of 0.04 cc. of 0.01 N permanganate is all that is necessary.

Calculations.

From the permanganate equivalent of 0.3 cc. of 0.1 N oxalic acid is subtracted twice³ the number of cc. of 0.01 N permanganate used in the final titration, the latter number, however, having been diminished by the amount of permanganate (0.04 cc.) necessary to give a permanent pink color to water. The result is multiplied by 0.2, since 1 cc. of the 0.01 N permanganate is equivalent to 0.64 mg. of calcium oxalate or 0.2 mg. of calcium.

Preparation of Reagents.

0.1 N Oxalic Acid.—0.1 N sodium oxalate solution (Sörenson) is made up and a potassium permanganate solution standardized against it. This solution then serves to standardize the N solution of oxalic acid. This N solution is quite permanent if kept in a cool place in the dark, and from it 0.1 N oxalic acid in 0.5 sulfuric acid may be prepared whenever needed.

0.01 N Potassium Permanganate.—An approximately 0.01 N solution of potassium permanganate is made by diluting a N or 0.1 N solution and the factor determined by titrating against the known 0.1 N oxalic acid solution. Filter before using.

³ Since half the total quantity is titrated.

PROTOCOLS.

1 cc. samples of Solution B⁴ which contained approximately the amount of inorganic phosphate found in blood serum were treated as described in the precipitation method, except that no oxalic acid was added. No precipitate appeared at the end of 48 hours. To three other samples 0.1 cc. of a solution of ammonium phosphate (4.84 gm. to 200 cc.) was added, and the procedure repeated. In spite of this large amount of phosphate no precipitate appeared. Samples of Solution B were analyzed. The results are given in Table I.

TABLE I.
Analyses of 1 Cc. Samples of Solution B (2).

Specimen No.	Calcium	
	Found	Present
	mg.	mg.
1	0.190	
2	0.190	
3	0.188	
4	0.188	
5	0.191	
6	0.187	
7	0.190	
8	0.188	
9	0.188	
10	0.190	
Average	0.189	0.193

Known quantities of calcium were added to sera of previously determined calcium content. Results are given in Table II.

⁴ Composition of Solution B.

NaCl.....	4.6340 gm.	KH ₂ PO ₄ was recrystallized and
KH ₂ PO ₄	0.0395 "	air-dried.
MgSO ₄	0.7577 "	CaCO ₃ from Iceland Spar.
CaCO ₃	0.2410 "	All other chemicals "Kahl-
HCl concentrated. 10.0	cc.	baum zur analyse."
H ₂ O.....up to 500	"	

Calcium in Blood Serum

TABLE II.
Recovery of Calcium Added to Serum.

Specimen No.	Calcium.			
	In serum.	Added.	Total present.	Total found.
	mg.	mg.	mg.	mg.
1	0.112	0 04	0.152	0.147
2	0.114	0 04	0 154	0.158
3	0.188	0 193	0 381	0.382
4	0.188	0 193	0.381	0.386
5	0.185	0 193	0 378	0.380

Table III contains a number of determinations on the sera of normal adults and of infants suffering from tetany.

TABLE III.
Calcium Determinations on Normal and Pathological Sera.

Specimen No.	Age.	Diagnosis.	Calcium per 100 cc serum.
			mg.
1	Adult.	Normal.	9.4
2	"	"	9.6
3	"	"	9.5
4	"	"	9.3
5	"	"	9.9
6	"	"	9.8
7	"	"	9.7
8	Placental blood.	"	11.1
9	" "	"	10.5
10	" "	"	10.4
11	7 yrs.	Acute chorea.	9.4
12	6 mos.	Tetany.	7.2
13	1 yr.	"	3.9
14	6 mos.	"	3.7
15	1 yr.	"	4.2
16	7 mos.	"	6.3
17	10 "	"	5.8
18	10 "	" (treated).	8.1
19	3 yrs.	Epilepsy.	10.7
20	5 "	Multiple neuritis.	9.6

DISCUSSION.

The sources of error in the determination of small quantities of calcium in the presence of magnesium and phosphates are: (a) the presence of traces of calcium in the reagents, especially those used in concentrated solution; (b) the precipitation of calcium in part as secondary calcium phosphate and of magnesium as magnesium oxalate due to the large excess of oxalate ions and an insufficient degree of acidity; (c) calcium oxalate is not entirely insoluble in water. 1 liter of water will dissolve 6 mg. of calcium oxalate (9) and 1 cc. of water containing both ammonium oxalate and ammonium chloride will dissolve at least 0.001 mg. of calcium (5); hence the danger of loss through too energetic washing, especially when a large excess of oxalates is used. (d) The preciseness of the end-point in the final titration has been questioned. The exact technique whereby this defect may be overcome has already been described. By using few reagents, errors due to introduction of calcium are avoided. Concentrated sulfuric acid and concentrated ammonia reagents are usually calcium-free, whereas even chemically pure ammonium chloride contains considerable amounts of calcium. Sodium acetate, c. p. (J. T. Baker), can also be obtained calcium-free. The precipitation of magnesium oxalate is avoided by adding 0.1 N oxalic acid in 0.05 sulfuric acid in relatively slight excess in small portions, so that most of it is added after the greater part of the calcium has been precipitated. It is rather surprising that such a slight excess of oxalic acid suffices to precipitate all the calcium. That phosphate is not precipitated under the above described experimental conditions has already been shown. The loss due to washing is, of course, entirely avoided in this method.

CONCLUSIONS.

A method has been described whereby the calcium in 2 cc. of serum may be determined with a maximum error of 3 per cent. In individual determinations of a series the error may often be less than 1 per cent.

Previously reported observations on the calcium content of the blood serum of infants suffering with tetany have been confirmed (2).

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DETERMINATION OF MINUTE AMOUNTS OF ACETONE BY TITRATION.*

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In 1916 a study of the occurrence of acetone bodies in normal blood and urine was undertaken. As a preliminary investigation, a comparison of the different methods of the determination of minute amounts of acetone was made, and certain advantages which a volumetric method possesses over a nephelometric (Marriott, 1913-14 *b*) or a gravimetric one¹ (Van Slyke, 1917) led to the study and extension of the Messinger method given below. Since this modification was first described, various papers have appeared (Ljungdahl (1917), Lenk (1916), Richter-Quittner (1919)) dealing with the same subject.

Many different methods have been proposed for the determination of acetone, and some of these have been adapted to minute quantities of acetone. The method of Scott-Wilson (1911) depends on the formation of a double compound of acetone and mercuric cyanide (Marsh and Fleming-Struthers, 1905), and subsequent titration of the mercury present in the precipitate formed by a modified Volhard technique. This method has been used for the determination of very small amounts of acetone by Marriott (1913-14 *b*), who measured the precipitate with a nephelometer, and by Folin and Denis (1914), who use the colorimeter for the same purpose. In 1898 Denigès proposed a method depending on the formation of a compound of acetone and mer-

* A preliminary report of this method was made before the American Society of Biological Chemists in New York in 1916 (Hubbard, 1917).

¹ When this paper was reported, only a preliminary report of Dr. Van Slyke's method was available.

curic sulfate. The compound was crystalline, and could be weighed, or could be decomposed and the mercury determined by titrating with silver nitrate and potassium cyanide. This method has been studied by Oppenheimer (1899) and by Sammett (1913) and has recently been adapted by Van Slyke (1917) for the determination of minute quantities of acetone, who recommended either gravimetric determination of the final product, or the titration of the mercury by the method of Personne (1863). Engfeldt (1915) proposed a colorimetric method for this determination based on the qualitative method of Frommer (1905), using a color reaction given by acetone and salicylic aldehyde. Csonka (1916) studied this method, but did not find it applicable to very small amounts of acetone. Other reactions are available for demonstrating the presence of small amounts of acetone, and for determining large amounts quantitatively, but are not well adapted for the quantitative determination of very small amounts.

The Messinger (1888) titration method has been most used for the determination of acetone in biological work. This method depends on the formation of iodoform from acetone in an alkaline iodine solution. A known amount of standard iodine solution reacts with acetone in alkaline solution, and the excess of iodine is determined, after acidifying, with a standardized thiosulfate solution. The method based on an older one of Krämer (1880), in which the iodoform was weighed, was proposed by Messinger in 1888, and has since been much studied. The principal objection to it is the number of compounds which give a similar reaction.

Collischonn (1890) believed that the method was inaccurate for small quantities of acetone, but Geelmuyden (1896), Marriott (1913-14 *a*), and others came to the opposite conclusion. Marriott (1913-14 *a*) weighed out small amounts of pure acetone, diluted them with water, and found that values obtained on titration agreed with the theoretical ones. This work was done with solutions of iodine and thiosulfate of approximately 0.1 N concentration.

A few papers have appeared recently in which the use of more dilute solutions is described. Lenk (1916), Ljungdahl (1917), and Richter-Quittner (1919) have mentioned the use of such solutions, but have not described precautions necessary if they are to be used successfully. In a more recent paper Ljungdahl

(1919) has described some of these precautions. He recommends the use of the potassium biiodate solution described by Bang (1913) for the determination of blood sugar, and gives in detail many of the conditions which must be complied with if its use is to be satisfactory. Some of these conditions are the same as those found in working with iodine solutions prepared by the technique described in this paper. A comparison of solutions of biiodate with iodine solutions was made in the course of this work, and led to the conclusion that fewer precautions were necessary when iodine solutions prepared as described were used than when biiodate solutions were used.

0.01 *N* solutions of iodine cannot be accurately titrated with thiosulfate without the addition of an excess of potassium iodide (Treadwell, 1915), and 0.001 *N* solutions are even more unsatisfactory. It was found that if a solution of iodine in 3 per cent potassium iodide was used results of titrations were accurate. These solutions were prepared as follows:

A stock solution of iodine in potassium iodide was made by dissolving 13.13 gm. of iodine and 25 gm. of potassium iodide in 1 liter of water, and a solution of sodium thiosulfate of a corresponding strength by dissolving 25.65 gm. of the reagent in 1 liter of water. The solutions are 0.1 *N* \times 103.47 per cent and 1 cc. of either is equivalent to 1 mg. of acetone. They are the solutions described by Shaffer (1908-09).

The thiosulfate solution was kept in a brown bottle connected with a burette by a siphon, and was protected from the air by tubes containing soda-lime. The day after it was prepared it was standardized in the usual way against an equivalent solution of pure potassium biiodate containing 3.362 gm. per liter. The strength of the thiosulfate solution remained unchanged for several months. The iodine solution was standardized against this, and restandardized from time to time, as its strength varied slightly even when kept in a colored bottle.

From these stock solutions dilution was made, using calibrated glassware. Water from a Barnstead still, which has a device for boiling water to expel ammonia and other volatile substances, was used for this dilution, and for all other work with acetone (see also Ljungdahl, 1919). To make the dilute iodine solutions, enough potassium iodide was used to give a final concentration

of about 3 per cent, and the stock solution diluted to $\frac{1}{10}$, $\frac{1}{50}$, or $\frac{1}{100}$ of its original strength. These solutions are equivalent respectively to 0.1, 0.02, and 0.01 mg. of acetone. The thiosulfate solutions of corresponding strength were made by diluting the stock solution with distilled water, and were found to titrate correctly against the equivalent iodine or biiodate solutions. The strength of the iodine solutions remained unchanged for 2 or 3 days; after that it often increased slightly, probably due to oxidation of the relatively large amounts of potassium iodide present. The thiosulfate solutions were permanent for from 24 to 48 hours, but not for a longer time. No special precautions

TABLE I.

Effect of Strength of Acid and of Time on the Titration of Dilute Iodine Solutions.

Iodine		Thiosulfate.	Acid concentration (H ₂ SO ₄).	Titrated at once	Titrated after 30 min.
Strength.	Amount	Strength			
	cc			cc.	cc
0.001 N	10	0.001 N	0.5 N	10.0	10.8
0.001 N	10	0.001 N	0.25 N	9.93	9.97
0.001 N	10	0.001 N	Slight excess.	9.97	9.93

Volume of each solution equals 50 cc.

were taken in preparing these solutions, as it was found more convenient to make a freshly diluted solution of thiosulfate daily.

In titrating with these dilute solutions certain precautions were necessary. All solutions of sodium hydroxide gave a slight blank, the size of which depended on the amount and grade of the sodium hydroxide used. It was found that this blank was constant if the alkaline iodine solutions were allowed to stand for 10 minutes, and that it did not increase in $\frac{1}{2}$ hour; if a good grade of sulfuric acid in not too great excess (a final excess of 0.25 N or less) was used for acidifying; and if the solution was titrated within 15 minutes after adding the acid.² Table I shows the effect of excess of acid on the titration of dilute iodine solutions.

² Some grades of sulfuric acid contain substances which react with iodine solutions, and it was found advisable to allow the acidified solution to stand for 5 minutes before titrating. If the sulfuric acid is boiled for 10 minutes, this error is decreased.

TABLE II.
Effect of Volume and Time on the Titration of Alkaline Iodine Solutions.

Solutions		50 cc volume			100 cc volume			150 cc volume			200 cc volume		
Iodine. Strength	Amount	Thiosulfate Strength.		1 min	5 min	30 min	1 min	5 min	30 min	1 min	5 min	30 min	1 min
		cc.		cc.	cc.	cc.	cc.	cc.	cc.	cc.	cc.	cc.	cc.
0.01N	10		0.01N	9.97		9.95	9.93		9.92	9.92		9.88	9.92
0.01N	20		0.01N	19.83		19.87	19.87		19.92	19.92		19.88	19.90
0.002N	5		0.001N	9.80		9.10							
0.002N	10		0.001N	19.55	19.00	18.92	19.65	18.80	19.67	18.80			

1 cc. of a strong sodium hydroxide solution (100 gm of NaOH+100 cc. of H₂O) added, and the alkaline iodine solution allowed to stand as shown before acidifying.

The volume of the solution also affects the value of the blank in certain cases. If 0.001 *N* iodine solutions are used, the volume of the solution must be kept practically constant; when 0.002 *N* solutions are used, the volume may vary from 50 to 100 cc., but should not be more dilute; with 0.01 *N* solutions the variation may be very much greater. The value of the blank is so small that the determination with the stock solutions is not affected (Table II).

When small amounts of acetone were determined, it was found necessary to insure the addition of sufficient alkali. Table III gives some results obtained with a solution of acetone containing

TABLE III.

Effect of the Concentration of Alkali and of Time on the Formation of Iodoform.

Stood alkaline.	Acetone present	Approximate normality.					
		0.2 <i>N</i> NaOH found	0.15 <i>N</i> NaOH found.	0.12 <i>N</i> NaOH found	0.10 <i>N</i> NaOH found	0.07 <i>N</i> NaOH found.	0.04 <i>N</i> NaOH found.
min.	mg.	mg.	mg.	mg.	mg.	mg.	mg.
5	0.450	0.450	0.395		0.443		
7	0.450					0.415	
10	0.450	0.438	{ 0.452 0.439 0.445	0.448	0.447	0.439	0.382
15	0.450	0.449			0.455		
20	0.450	0.448	0.452		0.435	0.448	
30	0.450		0.455				

10 cc. of 0.01 *N* iodine used in this determination in each experiment.

about 0.5 mg. A final concentration of 0.1 *N* to 0.2 *N* sodium hydroxide gave complete formation of iodoform in 10 minutes, while smaller concentrations did not give complete formation within that time. The limitations described above and illustrated in Tables I to III were the only limitations found to the application of the method.

Method.

To acetone, contained in a volume of 50 to 100 cc., a known amount of iodine was added. If there was probably very little acetone present—such amounts as are obtained from a few cc.

of normal blood or urine—10 to 25 cc. of 0.00207 N (1 cc. = 0.02 mg. of acetone) iodine, diluted as described, were used; for amounts of acetone from 0.2 to 2.0 mg., such as are obtained from blood or breath of patients with a marked acetonemia, 25 cc. of a solution five times as strong were added; for larger amounts, such as are found in the urine of patients with marked acetonemia, the stock solutions as described by Shaffer (1908-09) were used. When amounts of acetone larger than 0.2 mg. were present it was found that the volume of solution in which the acetone was contained had little effect on the determination, and if several milligrams were present the reaction could be carried out in 300 cc., as accurately as in 50 cc. No matter what amount of acetone is present, enough iodine must be used to give a distinct excess of the reagent.

To the solution containing acetone and iodine, 2 cc. of a sodium hydroxide solution, made by dissolving 200 gm. of sodium hydroxide in 300 cc. of water, were added, and the solution was shaken well for a few seconds. Long shaking was not found necessary. After the solution had stood alkaline for 10 minutes or more, 1 to 2 cc. of sulfuric acid (1 part of concentrated acid to 1 part of water) were added, and the solution was titrated with 0.001, 0.01, or 0.1 N sodium thiosulfate. A little clear dilute starch solution was added before the end of the titration to serve as indicator. A blank was run every day to test the relative strength of the iodine and thiosulfate solutions, and the result calculated from the difference in value between the titration of this blank and that of the solution containing acetone. As stated above, dilute solutions of sodium thiosulfate were prepared daily.

Acetone solutions used were carefully purified by redistilling repeatedly from fused calcium chloride until the product boiled sharply at 56°C. Samples of this product, when weighed out in small pipettes, sealed, the seal broken under water, and the acetone solution made to volume after the method of Marriott (1913-14 *a*), gave values on titration that agreed with the theoretical ones. The samples analyzed were of the magnitude of 20 mg. Solutions of this pure acetone were diluted to appropriate strength, and were used for the determination of minute amounts of acetone. It was necessary to restandardize the strong solutions frequently, as all acetone solutions lose strength readily.

Tables IV and V give results obtained by the method described. The figures in the column headed "Present" correspond with figures calculated from parallel determinations carried out on the strong acetone solutions from which the dilute solutions used were prepared.

Since it was desired to test the effect of repeated distillation from various solutions upon acetone, a few experiments were carried out on the loss of acetone when exposed to the air under

TABLE IV.
Results on Solutions of Pure Acetone.

Solutions used.	Present.	Found.
	<i>mg.</i>	<i>mg.</i>
0.00207 N iodine and 0.001035 N thiosulfate.	0.0046	0.0049
	0.00916	0.0104
	0.0229	0.0227
	0.0458	0.0458
	0.0916	0.0900
	0.2290	0.2345
0.01035 N iodine and 0.01035 N thiosulfate.	0.045	0.038
	0.090	0.082
	0.225	0.218
	0.450	0.450
	0.900	0.887
	2.250	2.235

various conditions. It appears from the table that the percentage loss of acetone under constant conditions varies with the volume of the solution used, but is practically independent of the amount of acetone present. The loss varies with the amount of surface of the solution and with temperature, as was expected, but, if the volume of solution is 100 cc., there is very little more loss at 37°C. than at 20°C. (see Table V). If solutions were sealed there was no change in acetone content of jars exposed to room temperature for 2 hours.

TABLE V.
Loss of Acetone on Standing.

Volume.	Acetone.	Time of standing						Notes.
		½ hr.		1 hr.		2 hrs		
cc.	mg.	mg.	per cent	mg.	per cent	mg.	per cent	
50	7.15	6.79	95	6.49	91	5.69	80	In 200 cc. Erlen- meyer flasks.
50	0.674	0.621	92	0.601	89	0.546	81	
100	7.15	7.06	99	6.95	97	6.58	92	
100	0.674	0.663	99	0.653	97	0.628	93	
50	6.43	5.82	91	5.47	85	4.87	76	In small specimen jars, diameter 6 cm.
100	6.43	6.12	95	5.92	92	5.52	86	
150	6.43	6.27	98	6.04	94	5.72	89	
50	6.43	3.85	60	3.30	51	1.75	27	In large specimen jars, diameter 16 cm.
100	6.43	4.70	73	4.40	68	2.85	44	
150	6.43	4.98	77	4.85	75	3.50	55	
50	8.15					6.20	76	Small specimen jars at room tempera- ture, 20°C.
50	20.60					15.75	76	
100	8.15	7.65	94	7.20	88	6.70	82	
100	20.60	19.42	94	18.60	90	17.17	83	
50	8.15			6.10	75			Small specimen jars heated to 38°C. in incubator.
50	20.60			14.95	73			
100	8.15			7.20	88			
100	20.60			17.98	87			

Distillation of Acetone from Various Oxidizing Reagents.

In order to separate acetone from various other compounds which also react with alkaline iodine solutions, it may conveniently be distilled from various reagents. Table VI gives results obtained by distilling acetone solutions from sodium peroxide; sulfuric acid plus potassium permanganate; sulfuric acid plus potassium dichromate; and by repeated distillation from sodium peroxide. The amount of acetone under the heading "Control" was measured and titrated simultaneously with the specimen oxidized. Table VI shows that acetone is not oxidized, under the conditions described, by sodium peroxide or by sulfuric acid plus potassium dichromate, or by sulfuric acid plus potassium

permanganate if the concentrations of acid and permanganate are properly regulated; if the volume is about 150 cc. and the concentration of sulfuric acid about 0.5 N, and 0.2 gm. of potassium permanganate is added, from 0.07 to 20 mg. of ace-

TABLE VI.
Distillation of Acetone from Oxidizing Reagents.

From Na_2O_2 .*			From $\text{H}_2\text{SO}_4 + \text{KMnO}_4$.						Notes.
Na_2O_2	Control.	Found.	Vol- ume.	H_2SO_4	KMnO_4	Control.	Found.		
gm.	mg.	mg.	cc.	cc.	gm.	mg.	mg		
			150	25	Few crystals.	7.68	7.70		
0.25	6.90	6.70	150	25	0.1	7.70	7.40		
0.25	6.78	6.80	150	25	0.2	7.70	6.90		
0.25	6.70	6.75	150	10	0.1	19.82	19.60		
0.5	0.0757	0.0749	150	10	0.2	19.87	19.17		
0.5	3.64	3.70	150	5	0.2	0.0757	0.0763		
0.5	6.85	6.85	150	5	0.2	0.682	0.682		
0.5	17.38	17.25	150	5	0.2	19.82	19.60		
0.5	18.60	18.32	150	5	0.3	7.05	6.92		
0.5	35.80	36.15	100	10	0.1	7.85	7.65		
1.0	6.73	6.55	100	5	0.2	20.02	19.54		
1.0	6.78	6.78							
1.0	14.05	14.10							
2.0	7.10	6.25							
2.0	6.83	6.97							
From $\text{H}_2\text{SO}_4 + \text{K}_2\text{Cr}_2\text{O}_7$.									
			Vol- ume	H_2SO_4	$\text{K}_2\text{Cr}_2\text{O}_7$	Control.	Found.		
			cc.	cc.	gm.	mg.	mg.		
			150	25	1	0.816	0.827		
			150	25	1	7.60	7.67		
			150	25	1	19.95	19.80		
			100	25	1	7.60	7.53		

* Volume of 100 cc.

tone may be recovered quantitatively. If much greater concentrations of acid and permanganate are used, there is some loss of acetone, but the method can be applied safely to the separation of acetone from substances which are more easily oxidized by sulfuric acid-permanganate solution than acetone is.

Table VII shows more in detail the effect of prolonged exposure to some of these oxidizing reagents. A known amount of acetone was added to each of several flasks, with water to the volume indicated. Oxidizing reagents were then added, the flask was connected with a condenser and receiver, and placed on a boiling water bath. After the solution had stood in boiling water for from 10 to 30 minutes, the water bath was removed without disconnecting the flask, and the contents of the flask were distilled actively for 10 minutes. The acetone in the receiving flask was then titrated by the method described. Not more than 10 per cent of the acetone used was found in the receiving flask when an alkaline, acid, or neutral solution was heated on a boiling water bath for 30 minutes connected in this way. Controls were run as in the preceding experiments.

Table VII shows that sodium peroxide, except in very large amounts, does not oxidize acetone, nor do the concentrations of sulfuric acid and potassium dichromate tested. The table brings out more clearly than does the preceding one the effect of concentration of sulfuric acid and potassium permanganate in independently increasing oxidation. The concentrations of these two substances which gave no oxidation on distillation gave oxidation when heated under these conditions.

Table VIII presents the effect of the following treatment. Acetone was distilled from acid and redistilled from alkali to a volume of about 150 cc. To this distillate were added 5 cc. of sulfuric acid diluted with 1 part of water and 0.2 gm. of potassium permanganate; this was distilled to give a volume of about 100 cc. in the distillate. To this distillate was added 0.5 gm. of sodium peroxide and this was again distilled. This distillate was titrated by the method described.

The following substances treated as described above gave no reaction with alkaline iodine solutions: 10 cc. of saturated chloroform, gasoline, benzene, toluene solutions; 500 mg. of phenol, methyl alcohol, formaldehyde; about 400 mg. of ethyl alcohol

Determination of Acetone

TABLE VII.

Oxidation of Acetone on Boiling Water Bath.

Sodium peroxide.

Heated 10 min. on water bath.					Heated 30 min. on water bath.				
Acetone		Volume.	Na ₂ O ₂	Found	Acetone.		Volume.	Na ₂ O ₂	Found.
Initial.	Controls				Initial.	Controls			
mg.	mg.	cc.	gm.	mg.	mg.	mg.	cc.	gm.	mg.
7.12	6.54 6.70	100	0	6.55	7.20	6.68 6.80	100	0	6.80
		100	0.25	6.62			100	0.25	6.68
		100	0.50	6.82			100	0.50	6.80
		100	1.00	6.42			100	1.00	6.75
		100	2.00	5.94	7.12	6.60 6.40	100	2.00	6.05
		75	0.50	6.62					
		150	0.50	6.64					

Potassium permanganate and sulfuric acid.*

Acetone.		Volume.	Time of heating.	Acid.	KMnO ₄	Found
Initial.	Controls					
mg.	mg.	cc.	min.	cc.	gm.	mg
7.17	6.57 6.57	150	10	0	0.1	6.59
		150	10	5	0.1	6.27
		150	10	5	0.2	5.92
		150	10	10	0.1	6.19
		150	10	10	0.2	5.49
		150	10	10	Few crystals.	6.97
		150	10	25	" "	7.07
		150	10	25	0.1	5.37
7.10	6.91	150	30	5	0.1	6.08

Potassium dichromate and sulfuric acid.*

Acetone.		Volume.	Time of heating.	Acid.	K ₂ Cr ₂ O ₇	Found.
Initial.	Controls.					
mg.	mg.	cc.	min.	cc.	gm.	mg.
7.87	7.57	150	30	25	1	7.55
	7.62	150	30	25	1	7.75

* Sulfuric acid is about 20×N.

(probably partially removed by the repeated fractional distillation (Richter-Quittner, 1919) and partially by oxidation), 50 mg. of acetaldehyde, and 50 mg. of ether.³ Various normal urines and bloods have been analyzed by this technique, and they gave values of from 0.01 to 0.03 mg. of acetone in the 10 cc. samples taken.⁴

TABLE VIII.

Successive Distillation of Acetone from Different Reagents.

Reagents used.	Control.	Found.
	mg.	mg.
Distilled successively from H_2SO_4 , NaOH,	0.264	0.248
$\text{H}_2\text{SO}_4 + \text{KMnO}_4$, and Na_2O_2 .	0.664	0.669
Control measured and titrated when the solu-	0.664	0.661
tion was. It was exposed to the air during	1.303	1.361
oxidation and distillation of the solution	1.605	1.608
studied.	3.44	3.44
	18 05	17.95

CONCLUSION.

A method has been described by which the Messinger titration method may be applied to dilute acetone solutions, certain reactions of acetone have been studied, and a method has been proposed by which small amounts of acetone can be separated from much larger amounts of alcohol and other interfering compounds.

My thanks are due to Dr. Philip A. Shaffer for his advice and assistance in this work.

³ Ether is oxidized by acid permanganate solutions as it is by dichromate solutions to give a compound which reacts like acetone (Short, 1920). If the ether present is less than 50 mg., this compound is removed by the subsequent treatment with sodium peroxide.

⁴ A paper in which this technique is applied to normal urine and blood is in preparation.

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DETERMINATION OF ACETONE IN EXPIRED AIR.*

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The fact that acetone is present in large amounts in the breath of patients suffering from severe diabetes has been known for a long time, and the high percentage of acetone which might occur in the breath was demonstrated by Geelmuyden in 1897. He injected acetone into rabbits, and showed that as much as 75 per cent of the acetone recovered might be found in the breath. In spite of these facts there are comparatively few quantitative determinations of acetone recorded in the literature, and almost all of these are in severe cases of diabetes.

One of the reasons for this is a lack of a convenient method for determining such small amounts of acetone as are found in the breath of normal subjects, or of subjects suffering from a moderate degree of acetonemia. Nebelthau (1897) had patients suffering from diabetes breathe directly through alkaline iodine solutions, after which he determined the amount of acetone by the Messinger (1888) titration. He admitted that this method was inexact, due to loss of iodine. Such a method can, however, be used to show the presence of acetone in breath, and has been adapted for its determination when present in large amounts by Marriott (1914), and for the determination of acetone in the air in chemical plants by Elliott and Dalton (1919). Scott-Wilson (1911) used the mercuric cyanide reagent described by him to demonstrate the presence of acetone in the breath of patients suffering from "acidosis," but did not describe a technique for a quantitative method. Geelmuyden (1897) described a method

* A preliminary report of this work was given before the meeting of the American Society of Biological Chemists in Baltimore in April, 1919.

Part of the work was carried out in the chemical laboratory of Harvard University through the courtesy of Dr. L. J. Henderson in February, 1919.

in which air from the lungs was oxidized in a combustion furnace, and the acetone calculated from the carbon dioxide so produced. He experimented with small animals in a Pettenkofer-Voit calorimeter. The air, drawn from the chamber through sodium hydroxide, passed to the furnace, where it was oxidized, and the carbon dioxide so obtained was caught in a second series of bottles of sodium hydroxide. Müller (1897-98) developed a technique which might be used with human subjects. He caused the patient to breathe through a series of four Woulff bottles containing 250 to 500 cc. of water kept cold by ice. The pressure of the water in the bottles was reduced by a pump capable of moving a large volume of air, and subjects could breathe for $\frac{1}{2}$ to 1 hour without discomfort. Acetone in the bottles was determined by the Messinger titration. This technique included in the determination other substances which react with alkaline iodine solutions and which may be present in the breath. Voit (1899) used this method of Müller, in connection with the Pettenkofer-Voit respiration chamber, to determine the effect of diet upon the excretion of acetone by small animals.

Folin and Denis (1915), in a study of the metabolism of two fasting women, have used a method based on the retention of acetone by a sodium bisulfite solution, and its subsequent determination with Scott-Wilson reagent, as described by them (Folin and Denis, 1914). Their patients breathed for 3 minutes through 10 cc. of 0.5 per cent sodium bisulfite solution. The results showed a marked increase of acetone during fasting, but did not show acetone in the breath of these patients on a normal diet. The method described below resembles this one in many essential features.

Folin and Denis (1914) have stated that acetone is retained almost as completely when blown through a 2 per cent solution of sodium bisulfite as is ammonia by a solution of hydrochloric acid. Preliminary tests showed that acetone in a stream of carbon dioxide from a Kipp generator was quantitatively retained by such a solution in spite of the decomposition of bisulfite.

Experiments were also made on the recovery of acetone added to sodium bisulfite solutions after distillation from sulfuric acid plus potassium permanganate and from sodium peroxide successively, a procedure which separates acetone from rather large

amounts of alcohol, acetaldehyde, and other interfering compounds.¹ To known amounts of acetone plus 2 gm. of sodium bisulfite in about 150 cc. of water, 10 cc. of 10 per cent sodium hydroxide were added, and the solution was distilled. The distillate was redistilled successively from sulfuric acid plus potassium permanganate and from sodium peroxide. Table I shows the results of such experiments. The maximum loss of acetone was about 6 per cent, and was not due to oxidation, as the same loss was shown by the control solutions exposed to the air.

TABLE I.
Recovery of Acetone Added to Bisulfite Solutions.

Description.	Acetone added	Acetone control	Thiosulfate.		Acetone recovered.
	mg.	mg.		cc.	mg.
2 gm. of NaHSO ₃ + acetone as shown, distilled from NaOH, and redistilled successively from H ₂ SO ₄ + KMnO ₄ , and from Na ₂ O ₂ as described. Control column gives results from acetone in about 100 cc. of water exposed to the air during the experiment. First six results show blanks by this method.	0.0			0.57	0.011
	0.0			0.88	0.018
	0.0		0.002N*	1.10	0.022
	0.0			0.45	0.009
	0.0			0.70	0.014
	0.0			0.56	0.011
	0.096	0.087	0.002N*	5.01†	0.102
	0.685	0.670	0.01N*	6.67†	0.667
	7.40	7.02	0.1N*	6.92†	6.92
	7.40	6.82	0.1N*	7.12†	7.12
		17.50	0.1N*	17.18†	17.18

* Approximate normality, true figure 103.47 per cent of these.

† Corrected for the blank given by the reagents.

Method.

For determining acetone in air, 75 cc. of a freshly prepared 2.5 per cent sodium bisulfite solution were measured into each of two bottles. The patient breathed through a mask (a celluloid etherizing mask with the valve removed), or through a mouthpiece. He received air through a simple valve placed in a vertical position to insure complete closure with expiration. The glass tubing used was 9.5 mm. and the bottles were 75 mm. in diameter. The amount of glass and rubber tubing was reduced to a minimum.

¹ Hubbard, R. S., *J. Biol. Chem.*, 1920, xliii, 43.

After the subject had breathed for 5 or 10 minutes (usually for 10 minutes) the bottles were disconnected, 10 cc. of 10 per cent sodium hydroxide were added to each, and the contents of each were washed separately into a 500 cc. Kjeldahl flask and treated as described below to remove interfering compounds already referred to. The solution was first distilled for 10 minutes through a water-cooled condenser into a second Kjeldahl flask containing enough water to cover the end of the receiving tube (Marriott, 1913-14 *a*) to give a final volume of about 150 cc. To the contents of the receiving flask 5 cc. of sulfuric acid (one part of concentrated acid plus one part of water) and about 0.2 gm. of potassium permanganate were added. The solution was then redistilled with the same precautions to give a volume of about 100 cc. in a third distilling flask. To this flask 0.5 gm. of sodium peroxide was added, and a final distillation made. This final distillation was made into a little distilled water to give a volume of between 50 and 100 cc., and the acetone determined by the technique described in the preceding paper,¹ or it was made into 25 cc. of Scott-Wilson reagent,² and the acetone estimated by the degree of turbidity produced.

If the latter method was used, standards containing approximately the same amount of acetone were distilled into the same amount of reagent; all solutions were made to 100 cc., and the turbidities produced were compared in Nessler tubes. By this method readings could be made within 0.005 mg. For more exact determinations, solutions were compared with the nearest standard either in a nephelometer (Marriott, 1913-14 *b*), or, if more than 0.2 mg. of acetone was present, in a colorimeter according to the technique of Folin and Denis (1914).

Usually slight blanks were obtained whether the acetone was determined by the Messinger titration or by the turbidity method. Blanks by the iodine method are given in Table I, blanks by the turbidity method were usually about 0.007 mg., and were prob-

² Scott-Wilson's reagent may be prepared as follows (Marriott, 1913-14 *a*, p. 284, foot-note): "Mercuric cyanide, 10 grams; Sodium hydroxide, 180 grams; Water, 1200 cc. The solution is agitated in a flask and 400 cc. of a 0.7268 per cent solution of silver nitrate slowly run in." The solution should be prepared at least 24 hours before it is used, and should be filtered if it is not perfectly clear.

ably produced by a trace of ammonia. The source of the blanks found with the iodine method was in the distillation from sodium peroxide, and probably arose from oxidation of some compound (possibly fat) which produced a substance that reacted with alkaline iodine solutions. To keep this blank constant, the flasks used for the last distillation must be kept free from grease, and the amount and approximate concentration of sodium peroxide must be kept fairly constant. Table II gives results on a series of normals in which the two methods are compared. The values are corrected for the blanks.

TABLE II.
Comparison of Results by Iodine and Turbidity Methods.

Subject.	Turbidity method. Found.	Iodine method. Found
	mg.	mg
R. S. H.	0.035	0.040
M. L.	0.015	0.015
Mrs. S.	0.007	0.007
Dr. O.	0.025	0.025
N. B.	0.025	0.025

Each subject breathed for 10 min. in both tests.

To find out whether the oxidation by permanganate and sodium peroxide caused any change in the value obtained, samples of breath collected as described were distilled from alkali and acid only, to remove sulfurous acid and ammonia, and other samples of breath, obtained as nearly simultaneously as possible, were analyzed by oxidation. By iodine titration values as much as 50 per cent lower were obtained after oxidation; by the turbidity method, results after oxidation agreed with those obtained after distillation within 0.005 mg. There is, therefore, in normal breath a substance, not acetone, which reacts with alkaline iodine solutions, and which is removed by oxidation with acid permanganate and sodium peroxide. This substance does not react with Scott-Wilson's reagent. The agreement of the results obtained by Scott-Wilson's reagent after oxidation with results after distillation shows an absence in the breaths studied of appreciable amounts of secondary propyl alcohol, or other compounds

which can give acetone on oxidation with potassium permanganate.

To show the completeness with which acetone can be recovered from the breath by the apparatus described, two experiments were run. First, a normal subject breathed through three bottles of 2.5 per cent sodium bisulfite instead of two, and the contents of the third bottle were analyzed with negative results; second, a bottle containing a known amount of acetone in 75 cc. of water was placed between the valve and the first bottle containing bisulfite. Table III gives a record of several such experiments, and shows a high percentage of recovery of relatively large amounts of acetone.

TABLE III.

Recovery of Acetone Added to Breath.

Description.	Pres- ent	Resi- due	1st bottle	2nd bottle.	Total recov- ered.
	mg.	mg.	mg.	mg.	mg
Breathed 10 min. through bottle containing known amount of acetone into two bottles containing NaHSO ₃ solution.	3.88	1.43	0.98	0.83	3.24
	3.88	1.66	1.40	0.41	3.47
	2.65*	0.75	1.25	0.70	2.70
	2.65*	0.30	1.70	0.50	2.50
	2.65*	0.30	1.65	0.45	2.40
	1.50	0.78	0.51	0.28	1.57

* Experiments in which acetone was warmed to 50°C.

To prove the efficiency of the mask, a bottle containing 75 cc. of 2.5 per cent sodium bisulfite was connected with the Benedict portable respiration apparatus (a closed circuit respiration system) (Benedict, 1918) in such a way that the air from the subject passed through this bottle before it passed through the bottle of soda-lime used to absorb CO₂. By this arrangement sulfur dioxide was absorbed, and did not reach the subject's mouth. Preliminary tests showed that as much as 5 mg. of acetone introduced into the machine were recovered quantitatively. Comparative tests using this calorimeter, and the mask and two bottles, gave the same value for acetone within 0.002 mg. Experiments were run to determine whether the presence of this bottle of

sodium bisulfite had any effect on the determination of metabolism by the apparatus, and showed that there was no such effect.

Table IV shows the results of the method on a series of normal subjects. These results were obtained by using the face mask, and analyzing with Scott-Wilson's reagent after oxidation with

TABLE IV.
Results of Turbidity Method on Normal Subjects.

No and sex.	1st bottle.	2nd bottle.	Total determination.	Per hour.
	<i>mg.</i>	<i>mg.</i>	<i>mg.</i>	<i>mg.</i>
4♂	0.068	0.013	0.081	0.49
5♀	0.018	0.011	0.029	0.17
6♀	0.018	0.008	0.026	0.16
9♂	0.042	0.013	0.055	0.33
10♂	0.033	0.010	0.043	0.26
11♀	0.033	0.010	0.043	0.26
13♂	0.015	0.008	0.023	0.14
14♀	0.038	0.010	0.048	0.29
15♀	0.038	0.010	0.048	0.29
16♂	0.023	0.008	0.031	0.19
18♀	0.028	0.008	0.036	0.22
21♂	0.023	0.010	0.033	0.20
22♂	0.038	0.018	0.056	0.34
23♀	0.023	0.005	0.028	0.17
24♀	0.023	0.010	0.033	0.20
25♂	0.028	0.008	0.036	0.22
28♀	0.028	0.011	0.039	0.23
35♀	0.028	0.005	0.033	0.20
37♂	0.023	0.003	0.026	0.16
38♀	0.028	0.013	0.041	0.25
40♂	0.068	0.018	0.086	0.52
42♀	0.053	0.028	0.081	0.49

Each subject breathed 10 min.

potassium permanganate and sodium peroxide. The results are corrected for the slight blank given by the reagents.

Table V shows the agreement which was found between duplicates, when the subject breathed for different periods within the same hour, and the different results obtained on the same subject on different days. A few results on cases showing an acidosis are included.

TABLE V.
Acetone in Breath.

No.	Subject.	Date.	Breathed.	1st bottle.	2nd bottle.	Total.	Per hour.	Remarks.
		1919	min.	mg.	mg.	mg.	mg.	
3	A ♂	Apr. 15	10	0.028	0.013	0.041	0.25	Normal subject.
33	"	" 19	10	0.063	0.018	0.081	0.49	Nos. 33 and 34 determined in the same hour.
34	"	" 19	5	0.038	0.011	0.049	0.59	
39	"	" 20	10	0.038	0.023	0.067	0.37	
1	B ♂	" 12	10	0.03	0.01	0.040	0.24	Normal subject.
2	"	" 12	10	0.025	0.005	0.030	0.18	Nos. 29, 30, and 31 done within the same hour.
29	"	" 16	2	0.023	0.005	0.028	0.84	
30	"	" 16	10	0.112	0.028	0.140	0.84	
31	"	" 16	5	0.058	0.018	0.076	0.91	
32	"	" 19	10	0.063	0.023	0.086	0.52	
17	C ♀	" 16	5	0.193	0.020	0.213	2.6	Diabetic; Legal positive.*
19	D ♀	" 16	5	0.010	0.003	0.013	0.16	" " negative.*
20	E ♀	" 16	5	0.058	0.023	0.081	0.97	" " positive.*
43	F ♂	" 21	5	1.113	0.133	1.25	15.0	Exophthalmic goiter.
44	G ♂	" 22	10	0.713	0.164	0.88	5.24	Diabetic; Legal positive.*

* Legal's reaction done on urine at the same time that the breath sample was obtained.

SUMMARY.

In the paper given above a convenient method is described by which acetone can be determined in the expired air by iodine titration or by precipitation with Scott-Wilson's reagent after removal of such interfering compounds as primary alcohols, aldehydes, phenols, and the simple cyclic hydrocarbons. Close agreement of results obtained by these chemically different methods of determination on the breath of normal subjects indicates strongly that the compound so determined is acetone. A series of results obtained by the method on normal subjects and on a few pathological cases is included.

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BIOCHEMICAL CHANGES IN THE FLESH OF BEEF ANIMALS DURING UNDERFEEDING.*

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INTRODUCTION.

There have recently appeared in the literature two papers dealing with the biochemical changes in the muscle of the salmon during the fast of spawning migration. The first paper¹ showed that besides experiencing a loss of muscular tissue these fish exhibited an impoverishing of the muscular tissue that remained to the extent of from 10 to 30 per cent of the protein content. The organic extractives nevertheless remained rather constant in percentage of the tissue and even increased under certain conditions. The second paper² confirmed the work presented in the former and showed further that the concentration of amino nitrogen relative to the water content after an initial increase remained constant throughout the migration. The first investigator argued that the results indicate a storage of reserve protein in the salmon muscle.

The Material.

The data presented in this paper were derived from material collected and analyzed during the course of an extended experiment on the uses to which a beef animal puts its food. A part

* Published with the permission of the Director of the Agricultural Experiment Station.

Presented before the Division of Biological Chemistry, American Chemical Society, St. Louis, April 14, 1920.

¹ Greene, C. W., *J. Biol. Chem.*, 1919, xxxix, 435.

² Greene, C. H., *J. Biol. Chem.*, 1919, xxxix, 457.

of these data has been published in another connection.³ To this are added data concerning the classes of protein and the glycogen content in the muscles of the animals.

All the animals were of the Hereford-Shorthorn type of beef steer. Six of them had been very fat at 11 months of age. The one which was least fat was killed as a control (No. 1) while the others were used in a special maintenance study. One of these was allowed sufficient food to permit of a gain of $\frac{1}{2}$ pound daily for 6 months (No. 2). Two were kept at constant weight for 6 (No. 3) and 12 months (No. 4). Two others were fed so as to allow a loss of $\frac{1}{2}$ pound per day for 6 (No. 5) and 10 months (No. 6). All the latter animals lost greatly in flesh, especially No. 6 which was in daily danger of dying near the end of the 10 months period. In this case it was clear that the animal had not been receiving sufficient protein in its diet to provide for the considerable skeletal growth which it exhibited and to provide for its maintenance.

Methods of Analysis.

The animals were slaughtered at the end of their experimental periods and a series of weights and measurements was recorded. Various composite and individual samples of the animals were analyzed fresh for water, protein, fat, ash, and phosphorus. Also cold water extracts were made of the flesh, and the nitrogen distribution was studied. The carcasses were hung in coolers for 2 days after slaughter in order to give a good quality of carcass to cut up into the various wholesale cuts. They all lost some moisture in this process which varied from 2.6 to 3.5 per cent of the total weight of the animals (exclusive of the contents of the digestive and excretory tract).

The cold water extracts of the flesh were analyzed for total solids, ash, nitrogen, and phosphorus. The nitrogen coagulated on heating and concentrating (10:1) in the presence of freshly precipitated magnesium carbonate and the nitrogen not precipitated in the cold (15°C.) with 15 per cent sodium chloride and 7.2 per cent tannic acid were also determined. The soluble nitrogen

³ Trowbridge, P. F., Moulton, C. R., and Haigh, L. D., *Missouri Agric. Exp. Station, Research Bull.* 28, 1918.

could thus be divided into the fraction coagulated on heating, the fraction not coagulated on heating but precipitated with salt and tannic acid, and the fraction not coagulated on heating or on the addition of salt and tannic acid. These fractions will be called albumins, albumoses and peptones, and amino-acids and extractives.

Water extracts of the blood were prepared by shaking the coagulated samples of blood with 10 to 15 gm. of sand and successive small quantities of water and allowing the mixture to settle. The clear liquid was poured off and the process continued until a volume of 500 cc. was obtained. This was heated and concentrated one-half. The resulting filtered solution was treated as was the water extract of the flesh. It still contained some nitrogen coagulable on heating and concentrating (10:1) with magnesium carbonate.

Samples of shoulder meat and the liver of each animal were sent to the laboratory within from 1 to 2 hours after slaughter and the glycogen content was determined by treating the well ground sample with about twice its volume of strong potassium hydroxide solution and digesting. From the resulting solution the glycogen was precipitated by adding an equal volume of 95 per cent alcohol. After it was purified the glycogen was hydrolyzed to dextrose and this was determined by Fehling's solution. For details the original papers must be consulted.⁴ The time elapsing between the last meal and slaughtering varied from 2 to 9 hours. The time elapsing between slaughter and the addition of the alkali varied within narrower limits; *i.e.*, from 1 to 2 hours after slaughter.

The methods of analysis were in general those of the Association of Official Agricultural Chemists. Moisture was determined by means of the vacuum desiccator and sulfuric acid. Fat was determined indirectly by ether extraction, nitrogen by the Kjeldahl-Gunning-Arnold method, ash by ignition in porcelain crucibles, and phosphorus on the ashed sample by the gravimetric method. In the water extracts phosphorus was determined after digestion of the evaporated solution with sulfuric acid.

⁴ Trowbridge, P. F., and Francis, C. K., *J. Ind. and Eng. Chem.*, 1910, ii, 21, 215.

Selection of Samples and Method of Computing Data.

The presence of stored material in the flesh, such as fat and glycogen, tends to obscure the true relations existing in the tissues. The data are presented on the original wet and fat-containing basis, and to do away with the diluting influence of the fat the data are also shown on the fat-free basis, or on the protoplasmic basis of Greene.¹ I wish to commend this method of computation and to deplore the usual method employed by chemists of calculating to a water- and fat-free basis.

The data are not calculated to the glycogen- and dextrose-free basis because full data on the glycogen and dextrose content are lacking and the amount is comparatively small and not much affected by the state of nutrition. The glycogen content of the shoulder muscle of the extremely emaciated animal (No. 6) was 0.514 per cent. on the fat-free basis while a very fat steer of the same age showed 0.459 per cent on the same basis and the control animal (No. 1) had but 0.170 per cent. Since this latter was one of the first animals slaughtered it may well be that the lack of experience with the method of determining glycogen accounts for the low result.

Changes in the Proteins of the Flesh.

Table I presents the data on the changes in composition of the flesh. The water content on the fat-free basis varied from about 76 to 77 per cent. The lower value is shown for a very thin steer as well as for the fat steers. The higher value is found only in the case of the animals whose ration made them grow thinner after having been fat at 11 months. It is not argued, however, that the thinness of the animal is responsible for the higher water content.

The young and old fat steers show between 3.5 and 3.6 per cent of nitrogen in the flesh on the fat-free basis. No. 2 showed a decrease of about 6 per cent, as did the other animals on lower planes of nutrition. The animal subjected to the most extreme treatment (No 6) shows only 3.18 per cent, a decrease from the fat animals of 10 per cent in total nitrogenous matter. This steer has lost 89.5 kilos in body weight, 44.8 kilos of which was lean

TABLE I.
Composition of Composite Flesh.

Animal No.....	1	2	3	4	5	6	7
Class.....	Control.	Super-maintenance.	Maintenance.	Maintenance.	Sub-maintenance.	Sub-maintenance.	Full fed.
Condition.....	Fat.	Fat.	Fairly fat.	Thin.	Very thin.	Very, very thin.	Very fat.
Age.....	11 mos.	17 mos.	17 mos	23 mos	17 mos.	21 mos	21 mos.
	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Water.....	{ Fresh. 62.28	60.62	61.89	70.52	71.20	76.37	51.24
	{ Fat-free. 76.42	75.99	77.05	77.04	75.83	77.04	75.98
Fat, fresh.....	18.50	20.22	19.67	8.47	6.10	1.87	32.55
Solids.....	{ Fresh. 37.71	39.37	38.10	29.48	28.79	23.63	48.75
	{ Fat-free. 23.57	24.00	22.94	22.95	24.17	22.96	24.01
Water-soluble solids.....	{ Fresh. 4.35	3.73	4.12	4.69	4.85	4.21	3.47
	{ Fat-free. 5.33	4.68	5.13	5.12	5.16	4.29	5.15
Ash.....	{ Fresh. 0.852	0.805	0.798	0.956	0.888	1.045	0.703
	{ Fat-free. 1.045	1.009	0.993	1.044	0.946	1.054	1.042
Water-soluble ash.....	{ Fresh. 0.766	0.493	0.647	0.709	0.776	0.890	0.604
	{ Fat-free. 0.940	0.618	0.805	0.775	0.826	0.907	0.896
Phosphorus.....	{ Fresh. 0.167	0.160	0.151	0.186	0.178	0.174	0.133
	{ Fat-free. 0.205	0.201	0.188	0.203	0.190	0.176	0.197
Water-soluble phosphorus....	{ Fresh. 0.127	0.119	0.117	0.143	0.141	0.128	0.089
	{ Fat-free. 0.156	0.149	0.146	0.156	0.150	0.130	0.132
Nitrogen.....	{ Fresh. 2.922	2.632	2.700	3.082	3.139	3.150	2.384
	{ Fat-free. 3.585	3.299	3.361	3.367	3.343	3.180	3.535
Water-soluble nitrogen.....	{ Fresh. 0.524	0.451	0.497	0.526	0.585	0.463	0.148
	{ Fat-free. 0.643	0.565	0.619	0.575	0.623	0.467	0.620
Insoluble nitrogen, fat-free.	2.942	2.734	2.742	2.792	2.720	2.713	2.915
Albumin nitrogen.....	{ Fresh. 0.239	0.176	0.195	0.240	0.262	0.152	0.156
	{ Fat-free. 0.293	0.221	0.243	0.262	0.279	0.153	0.231
Albumose peptide nitrogen..	{ Fresh. 0.100	0.106	0.123	0.084	0.112	0.108	0.099
	{ Fat-free. 0.123	0.132	0.153	0.092	0.133	0.109	0.147
Amino-acid extractive nitrogen.....	{ Fresh. 0.185	0.169	0.179	0.202	0.211	0.203	0.163
	{ Fat-free. 0.227	0.212	0.223	0.221	0.225	0.205	0.242

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flesh and 10.9 kilos of which was protein. Besides this loss the animal suffered a depletion in the richness of the remaining nitrogenous material of 10 per cent.

It is of interest to note what classes of nitrogenous matter contributed to this loss. In most of the thin steers the insoluble nitrogenous matter accounts for all the loss, but in the case of No. 6 it accounts for only part of the loss. The remaining loss was in the soluble nitrogen and especially the albumins which showed a

TABLE II.
Nitrogen Distribution in Composite Flesh.

Animal No.	1	2	3	4	5	6	7
Class.	Control.	Super-maintenance.	Maintenance	Maintenance	Sub-maintenance.	Sub-maintenance.	Full fed
Condition.	Fat.	Fat.	Fairly fat.	Thin.	Very thin.	Very, very thin	Very fat.
Age	11 mos	17 mos	17 mos	23 mos	17 mos	21 mos	21 mos.
	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Water-soluble N.....	17 93	17.12	18.41	17 07	18.63	14 68	17 53
Water-insoluble N.....	82 06	82.87	81.58	82.92	81.36	85.31	82 46
Albumin N....	8.17	6 69	7.23	7.78	8.34	4 81	6.53
Albumose and peptone N..	3.43	4.00	4 55	2.73	3.56	3.42	4 15
Amino-acid and extractive N.....	6.33	6.42	6 63	6 56	6.73	6.44	6.84
Amino-acid and extractive nitrogen per 100 gm. water.							
	mg.	mg.	mg	mg.	mg.	mg.	mg.
	297	279	289	287	297	266	318

loss from the control animal (No. 1) of 28 per cent. No. 6 also showed a loss of 10 per cent in the amino-acid and extractive nitrogen from the control (No. 1) or 18 per cent from No. 7.

The distribution of nitrogenous material in percentage of the total nitrogenous material is shown in Table II. It is seen that the water-soluble and water-insoluble nitrogen remain rather constant in all cases but No. 6 which exhibits a decrease of 4 per cent of the total in this fraction, all of which is due to the albumin fraction. The amino-acid and extractive nitrogen remains prac-

tically constant in all cases. The increase that is shown is believed to be due to increasing age. The flesh of older steers runs higher in flavor; *i.e.*, in the extractives. The concentration of the amino-acids and extractives per 100 gm. of water remains about constant except for No. 6 which shows a 10 per cent decrease from No. 1 or about 18 per cent decrease from No. 7.

The Other Constituents of the Flesh.

On the whole the total ash and water-soluble ash remain about constant on the fat-free basis. The total phosphorus is rather constant excepting for No. 6 which shows about a 13 per cent decrease. The same is true of the water-soluble phosphorus where No. 6 shows a decrease of about 15 per cent. No. 7 also shows a lowered value here while the 23 months old thin steer (No. 4) shows a maximum.

Changes in Composition of the Liver.

The ether extract (fat) of the liver varies as a rule between rather narrow limits. So the data shown in Table III are interpreted the same on either basis. The liver of No. 6 has the highest water content and the lowest content of solids. In spite of this it exhibits the highest nitrogen and ash content. The phosphorus content is slightly low in several of the steers but not in either of the fat steers. With a lowered content of solids in the liver of No. 6 there must be a lowered protein content and so the increased nitrogen content must be due to a larger proportion of products of catabolism of higher nitrogen content such as is shown by the nitrogenous extractives. It is unfortunate that a separation of the nitrogenous bodies of the liver had not been made. Perhaps too much emphasis had better not be laid on this apparent change in nitrogenous matter since the high value for nitrogen is the result of the average of the triplicate results, one of which was high. If the two nearest results are averaged the nitrogen content is normal. This point needs verification.

The glycogen content of the liver is of interest in this connection. In the control animal there was 0.601 per cent glycogen on the fresh basis. The fairly fat maintenance steer (No. 3) had 0.965

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per cent, No. 6 0.913 per cent, and No. 7 0.884 per cent. All these differences might well be due to differences in time which elapsed between feeding and slaughter and between slaughter and analysis of the sample.

TABLE III.
Composition of Liver.

Animal No.....	1	2	3	4	5	6	7
Class.	Con- trol.	Super- main- tenance	Main- tenance.	Main- tenance.	Sub- main- tenance.	Sub- main- tenance.	Full fed.
Condition.. . . .	Fat.	Fat.	Fairly fat.	Thin.	Very thin.	Very, very thin.	Very fat.
Age.....	11 mos	17 mos	17 mos	23 mos.	17 mos.	21 mos.	21 mos.
	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Water.....							
{ Fresh.	68.82	70.34	70.30	70.85	69.68	71.34	69.22
{ Fat-free.	72.64	71.94	72.24	73.31	71.22	74.11	70.94
Fat, fresh.....	5.26	2.22	2.69	3.36	2.17	3.73	2.43
Solids.....							
{ Fresh.	31.17	29.65	29.70	29.15	30.32	28.66	30.78
{ Fat-free.	29.35	28.05	27.75	26.68	28.77	25.88	29.05
Nitrogen.....							
{ Fresh.	3.06	2.97	2.95	3.19	3.49	3.65*	3.27
{ Fat-free.	3.23	3.04	3.03	3.30	3.59	3.79*	3.35
Ash.....							
{ Fresh.	1.340	1.443	1.376	1.473	1.453	1.540	1.352
{ Fat-free.	1.414	1.476	1.414	1.524	1.485	1.600	1.386
Phosphorus.....							
{ Fresh.	0.347	0.336	0.332	0.319	0.386	0.333	0.391
{ Fat-free.	0.366	0.344	0.341	0.330	0.395	0.346	0.410

* Average of triplicate results. When one high result is discarded these figures become 3.283 and 3.411, respectively.

Changes in Composition of the Blood.

Table IV shows the composition of the blood of the animals.

The water content of the blood varies with the fat content of the steer being higher in the thinner steers and lower in the fatter ones. A poor state of nutrition seems to give a "thinner" blood. No. 6 had 5 per cent more water in the blood than did No. 7.

Two of the steers show a very high ash content, the thin maintenance animal and the fasted steer (Nos. 4 and 6). Too much emphasis should not be placed upon this until it is confirmed by further work. The phosphorus content is lowest in No. 6. It is, however, fairly constant throughout for all animals but the control animal. The high result here may be an error since in the analysis of the blood from thirty-five animals only two had more than 0.030 per cent of phosphorus.

TABLE IV
Composition of Blood.

Animal No.	1	2	3	4	5	6	7
Class.....	Control	Super-maintenance	Maintenance.	Maintenance.	Sub-maintenance.	Sub-maintenance.	Full fed.
Condition.	Fat.	Fat.	Fairly fat.	Thin.	Very thin.	Very, very thin.	Very fat.
Age	11 mos	17 mos	17 mos	23 mos	17 mos	21 mos.	21 mos.
	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Water.....	79.34	80.57	80.60	80.63	81.20	83.68	78.65
Ash.....	0.318	0.358	0.339	0.747	0.322	0.800	0.387
Phosphorus.....	0.055	0.025	0.025	0.029	0.024	0.019	0.022
Total nitrogen.....	3.182	3.002	2.987	3.008	2.897	3.135	3.334
Water-soluble nitrogen	0.295	0.785	0.568	0.400	0.556	0.381	0.503
Albumin nitrogen...	0.048	0.434	0.338	0.040	0.257	0.086	0.332
Albumose and peptone nitrogen.....	0.186	0.288	0.157	0.239	0.176	0.263	-0.032
Amino-acid and extractive nitrogen.	0.061	0.063	0.073	0.121	0.123	0.032	0.203
Ratio N:P.....	57.9	120.1	119.5	103.7	120.7	165.0	152.0

The nitrogen content of the blood varies within rather narrow limits. The very fat steer (No. 7) had somewhat the highest content of nitrogen and the lowest is shown by the very thin submaintenance steer (No. 5). The results of the separation of nitrogenous bodies are unsatisfactory. The method employed gave rather large variations in the triplicate determinations and a lack of uniformity in the amount of coagulable nitrogen remaining in solution after the first heating. No attempt will be made to interpret the results shown. The method used should be improved or discarded.

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The ratio of nitrogen to phosphorus in the blood is shown in Table IV. Age seems to play a rôle in the change of ratio. No. 1 had a ratio of nitrogen to phosphorus of 57.9. The 17 months steers had about 120 irrespective of condition or plane of nutrition. The abnormally high phosphorus content of the control steer's blood is, perhaps, responsible for the low ratio of 57.9. With the animals 21 to 23 months old this ratio is very high in the case of both the very fat and the emaciated steer, about 160. The third steer shows a low value of about 104. Neither the condition of the steer nor the plane of nutrition seems to be responsible for the change.

Changes in the Size of the Muscle Fibers.

It has been shown that underfeeding decreased the weight of lean flesh about 44.8 kilos in an animal weighing about 300 kilos. The total loss of protein, calculated from the nitrogen content, was 10.9 kilos. The quality of the protein had been altered by a great decrease in the albumin fraction. Fig. 1 shows the changes in the muscle fibers that accompanied these changes. The fiber designated as "very thin" was from the biceps muscle of the fasted steer (No. 6). The other fibers were from the same muscles of others of the animals. The figure has been published in another connection⁵ but is shown again here with some added data.

There is little difference in the diameter of muscle fibers of very fat or thin steers, the former having a diameter of 50 micra and the latter 45 micra. No. 6, however, had fibers that had shrunk to 20 micra in diameter, but 40 per cent of the original diameter. The area of the cross section will vary as the square of the radius, or as 625:506:100. The cross section of No. 6's biceps fiber was one-fifth as great as that of a thin steer and one-sixth as great as that of a fat steer.

The length of the segments of the muscle fibers shows a similar decrease. For the fat steer the average length is 14.4 micra, for the thin steer 10.9 micra, and for the fasted steer 6.4 micra. This would argue that the muscle fiber had decreased over one-half in length.

⁵Waters, H. J., *Proc. 30th Meeting Soc. Promotion of Agric. Sc.*, 1909.

The volume of a segment is obtained from the formula for the volume of a cylinder, $\pi r^2 h$, where r is the radius of the fiber and h is the average length of the segment. In round numbers the relative volume of an average segment was 9,000 for the fat steer, 5,500 for the thin steer, and but 640 for the fasted steer. The

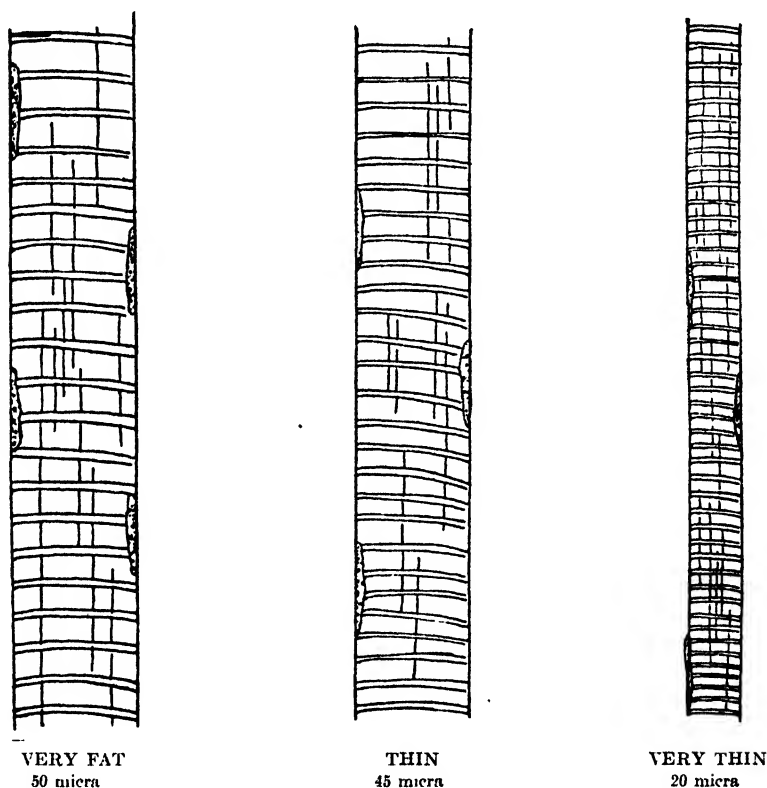


FIG. 1. The size of muscle fiber as influenced by underfeeding.

ratios are then 14.0:8.6:1. If this is any proper index of muscle volume the possibilities for change in size or volume are stupendous.

No evidence was found in this study of a disintegration of muscle fibers. The very thin fiber still functioned as a muscle fiber and it would appear that its vital structure must be intact. The

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change therefore must be due to a resorption of inter- and intracellular substances of a stored nature. Part of this no doubt was fat, but considerable of it was nitrogenous matter, as shown above.

It must be remembered that the thin and fasted steers had previously been as fat as the control steer and presumably had the same make-up of nitrogenous matter and the same size of muscle fibers. The change is one of resorption and stored protein has been removed.

A better histological picture of the muscle fibers would contribute materially to the force of the arguments presented. It is to be regretted that the figure is diagrammatic although based upon averaged observations made upon the muscle fibers of the steers.

SUMMARY.

Inanition or partial starvation does not cause a watery muscular tissue. Fat is almost entirely resorbed while glycogen apparently is not. The character of the protein is altered by a removal of nitrogenous substances amounting to 10 per cent of the total nitrogenous material and consisting of the albumin nitrogen. The phosphorus content of the flesh is reduced 13 to 15 per cent.

The liver has a somewhat higher water content in the starved animal accompanied by a high nitrogen content. This would indicate a greater proportion of amino-acid and extractive nitrogenous substances. The glycogen content is not depleted.

The blood has more water and less total nitrogen in the fasted steer.

The muscle fibers have become very much smaller, but still are functioning muscle fibers.

It is believed that the data presented indicate a storage of protein matter in the muscles of the beef steer.

AMINO-ACID SYNTHESIS IN THE ANIMAL ORGANISM.

CAN NOR-LEUCINE REPLACE LYSINE FOR THE NUTRITIVE REQUIREMENTS OF THE WHITE RAT?

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Of the possibility of amino-acid synthesis in the normal mammalian organism, little is definitely known. Perfusion experiments with the surviving liver (1) have shown that α -keto- and α -hydroxy-acids may be converted to the corresponding amino-acids, to the optical isomer that exists in the protein molecule. The formation of tyrosine, phenylalanine, alanine, leucine, and nor-leucine among others has thus been demonstrated. In the living organism, however, the synthesis of α -amino-acids by the reaction between ammonia and non-nitrogenous rests cannot be regarded as proved, despite the many experiments (2) which have been undertaken with this in view. Of amino-acids present in the protein molecule, only glycocoll is known to be synthesized, and even in the case of this amino-acid no proof exists as to whether it takes its origin from glycollic or glyoxylic acid and ammonia, a direct synthesis of the type discussed above, or whether it arises from cleavage of some other amino-acid of higher molecular weight (3). Tyrosine may possibly be derived from phenylalanine (4), and histidine from arginine (5), but neither of these reactions involves an amination of a non-nitrogenous carbon chain.

The present study is concerned with the formation of lysine by amination of the ϵ carbon of nor-leucine. It seemed possible that, if the α -amino group were already present in the molecule, further substitution of a second amino group might take place more readily. The possibility also suggested itself that, even if this formation of lysine from nor-leucine did not occur, nor-leucine might

still have a value in nutrition. According to the current idea, the ϵ group of lysine does not function in peptide synthesis and is present in the protein molecule free and not combined in the peptide linkage. The organism might have the power to synthesize a new type of protein under stress by the substitution of nor-leucine for lysine, a protein which would contain little or no free amino nitrogen, since it is to the ϵ group of lysine that this free amino nitrogen of the protein molecule is usually attributed.

The validity of the present experimental work is dependent upon the fact that lysine in adequate amounts is essential for the normal growth of the young white rat. Osborne and Mendel (6) have shown that gliadin with its low content of lysine as the sole source of the protein of the diet does not permit normal growth unless supplemented by lysine, while with zein (7), which is deficient in both tryptophane and lysine, as the source of protein maintenance results from the addition of tryptophane, but no growth unless lysine is also added. Hart, Nelson, and Pitz (8) were unable to demonstrate a synthesis of lysine by the mammary gland of the white rat, to supply an adequate milk for the young. Buckner, Nollau, and Kastle (9), and Osborne and Mendel (10) have also demonstrated that chickens require a sufficient amount of lysine to make normal growth.

Nor-leucine, the third of the isomeric α -amino-caproic acids known to exist in the protein molecule, was discovered by Abderhalden and Weil (11) in 1912 in the proteins of the central nervous system. However, it is in all probability also present in proteins derived from other sources, but since its solubilities and general properties so closely resemble those of the other isomeric α -amino-caproic acids as to make its separation from them difficult, its occurrence has as yet been reported in the proteins of the nervous system only. Greenwald (12) has demonstrated that nor-leucine behaves normally in the animal body, yielding its nitrogen as urea after ingestion. He has also observed that nor-leucine is a glucose-former in the phlorhizinized dog, and that the amount of glucose formed from the *d*, *l*, or *dl* forms does not vary appreciably.

EXPERIMENTAL.

Young white rats of 50 to 60 gm. weight for the most part were used as experimental animals. They were kept in individual cages which permitted accurate record of the food consumption. The usual precautions to insure cleanliness and prevent infection were taken. It may be noted that only one case of disease, a type of pulmonary infection, appeared in the colony. The food which was high in fat content was made into small balls weighing 5 to 10 gm. each which were kept in an ice chest until used. In this form the food was not easily scattered by the animal and there was little wasting.

The casein, gliadin, nor-leucine, and lysine were prepared in the laboratory. The lysine was obtained by hydrolysis of casein, while the nor-leucine was a synthetic product. The protein-free milk prepared by the method of Osborne and Mendel contained 0.59 per cent nitrogen. There has been considerable criticism of the use of this substance in nutrition experiments from time to time, but in the present series the objections offered seemed to be invalid, since the diet as a whole remained constant throughout with variations from the addition of small quantities of the amino-acids only. If there were any appreciable amounts of essential amino-acids furnished by the protein-free milk, these were present in each of the periods, and their influence should have been uniform.

The experimental dietaries were as follows:

	<i>per cent</i>		<i>per cent</i>
Casein or gliadin.....	18.0	Amino-acid.....	0.5
Protein-free milk.....	28.0	Gliadin.....	17.5
Corn-starch.....	24.0	Protein-free milk.....	28.0
Purified butter fat.....	18.0	Corn-starch.....	22.0
Lard.....	12.0	Purified butter fat.....	18.0
	<hr/> 100.0	Lard.....	<hr/> 14.0
			100.0

Rats were maintained on diets containing 18 per cent gliadin for periods of several weeks; nor-leucine replaced part of the gliadin usually in amounts equivalent to 0.5 per cent of the diet, the protein plus amino-acid still constituting 18 per cent of the total ration; finally in some experiments equivalent amounts of lysine

replaced the nor-leucine. The relative order of these periods was varied, but the general procedure remained the same. Controls were fed on casein rations to demonstrate that normal growth was possible on these diets provided the protein was adequate.

In some of the experiments, 1.5 per cent of nor-leucine was fed instead of 0.5 per cent. Lysine to the extent of 0.5 per cent will supplement a diet containing 18 per cent gliadin such as was used in these experiments (6) and allow normal growth. The nor-leucine, however, was racemic and as it was considered desirable to insure an adequate amount of the *d* form in the diet, in case the animal could not use both forms equally well, the higher percentages were added to the ration. In later experiments through the kindness of Dr. C. S. Marvel of this laboratory, we were supplied with small amounts of *d*-nor-leucine, which showed on analysis 82 per cent of the *d* form. This was added to the diet to the extent of 0.658 per cent equivalent to 0.5 per cent of the *d* form. No difference could be observed between this optically active form and the racemic compound.

DISCUSSION.

The results of the experiments are given in Table I and Charts 1 and 2. Rats fed on casein grew normally in all cases.¹ The curves for Rats 5, 8, and 17 show the type of growth obtained when gliadin was substituted for casein. Slight growth ensued, a result which was in agreement with the findings of Osborne and Mendel (6) previously discussed. Rat 3 was fed a diet in which 0.5 per cent *dl*-nor-leucine replaced an equivalent amount of gliadin. The curve of growth for this animal closely resembles that for the rats fed gliadin alone. Animals which received a higher percentage of the *dl*-nor-leucine (Rats 6, 8, 14, 17) did not make any better growth than those fed 0.5 per cent. The cessation of growth in older animals, which had been gaining in weight steadily on casein diets, when gliadin plus nor-leucine was substituted as the source of protein may be observed in the curves for Rats 11 and 12. In order to prove that this failure to increase in weight on gliadin and nor-leucine was not due to the

¹ The growth curves of the casein-fed controls are not shown in the charts, but Table I includes a record of their weights and food consumption.

TABLE I.
Summary of Weights and Food Intake of Experimental Animals.

Rat No	Diet.	Duration	Initial weight.	Final weight	Gain.	Total food.	Food per 100 gm. of rat	Gain per 100 gm. of food
		<i>days</i>	<i>gm</i>	<i>gm</i>	<i>gm</i>	<i>gm</i>	<i>gm.</i>	<i>gm</i>
1 ♂	Casein.	98	97	250	152	877	32	17 8
9 ♂	"	84	63	190	127	616	37	20 5
16 ♂	"	56	62	206	144	453	40	31 9
2 ♂	Gliadin.	91	100	117	16	456	34	3 7
13 ♀	"	91	68	88	20	451	50	4 3
3 ♂	(a) Gliadin.	28	101	101	00	152	37	0 0
	(b) " + 0.5 per cent <i>dl</i> -nor-leucine.	91	101	132	30	496	31	4 0
11 ♂	(a) Casein.	42	70	150	80	296	43	27 0
	(b) Gliadin + 0.5 per cent <i>dl</i> -nor-leucine.	91	150	149	-1.3	610	31	-0 2
12 ♀	(a) Casein.	42	70	130	60	275	44	22 0
	(b) Gliadin + 1.5 per cent <i>dl</i> -nor-leucine.	98	130	140	10	558	30	1 7
5 ♀	(a) Gliadin.	70	49	58	10	271	48	3 5
	(b) " + 1 per cent lysine.	42	58	113	54	243	40	22.2
	(c) Gliadin + 0.5 per cent <i>dl</i> -nor-leucine.	35	113	115	2.3	173	25	1.3
8 ♂	(a) Gliadin.	42	76	77	1	184	36	0 5
	(b) " + 1.5 per cent <i>dl</i> -nor-leucine.	84	77	88	11	349	33	3.1
	(c) Gliadin + 0.5 per cent <i>d</i> -nor-leucine.	42	88	91	3	171	31	1 7
	(d) Gliadin + 0.5 per cent lysine.	42	91	120	19	208	31	9 3
6 ♀	(a) Gliadin.	28	63	62	-1	133	43	-0 7
	(b) " + 1.5 per cent <i>dl</i> -nor-leucine.	56	62	74	11	230	38	4 8
	(c) Gliadin + 1 per cent lysine.	42	74	123	50	248	35	20 0
	(d) Gliadin + 0.5 per cent <i>dl</i> -nor-leucine.	35	123	126	2	205	28	1.2

TABLE I—*Concluded.*

Rat No.	Diet.	Duration.	Initial weight.	Final weight.	Gain.	Total food.	Food per 100 gm. of rat.	Gain per 100 gm. of food.
		<i>days</i>	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>
4 ♂	(a) Casein.	28	59	106	47	140	35	33.7
	(b) Gliadin + 0.5 per cent <i>dl</i> -nor-leucine.	63	106	118	12	397	34	3.0
	(c) Gliadin + 0.5 per cent lysine.	35	118	167	49	249	29	15.5
	(d) Gliadin + 1.5 per cent <i>dl</i> -nor-leucine.	35	167	160	97	234	24	-3.0
14 ♂	(a) Gliadin + 1.5 per cent <i>dl</i> -nor-leucine.	84	62	62	00	281	35	00.0
	(b) Gliadin + 0.5 per cent lysine.	35	62	97	35	143	35	24.4
	(a) Gliadin + 1.5 per cent <i>dl</i> -nor-leucine.	56	57	57	00	199	44	00.0
15 ♀	(b) Gliadin + 0.5 per cent <i>d</i> -nor-leucine.	42	57	65	8	110	30	7.2
	(a) Gliadin.	56	57	59	2	224	50	0.9
17 ♀	(b) " + 1.5 per cent <i>dl</i> -nor-leucine.	63	59	62	3	185	34	1.6

inability of the organism to resolve and metabolize the racemic amino-acid, Rats 8 and 15 were fed *d*-nor-leucine in place of the racemic form. The results differed in no way from those of the preceding experiments.

As a final check on the experimental procedures, lysine replaced the nor-leucine of the diet of Rats 4, 5, 6, 8, and 14 (Chart 2). In confirmation of the work of Osborne and Mendel, this amino-acid supplemented the diet in such a way as to permit normal growth. On the addition of lysine, there was a marked improvement in the general condition of the rats previously stunted by a gliadin or a gliadin plus nor-leucine diet, an improvement which was noticeable within the 1st week.

The increased rate of growth is not to be attributed to an increased food consumption, since as shown in the table the food eaten per 100 gm. of body weight in the lysine period was practically the same as in the preceding nor-leucine period. The gains per 100 gm. of food consumed on the lysine-gliadin diets were com-

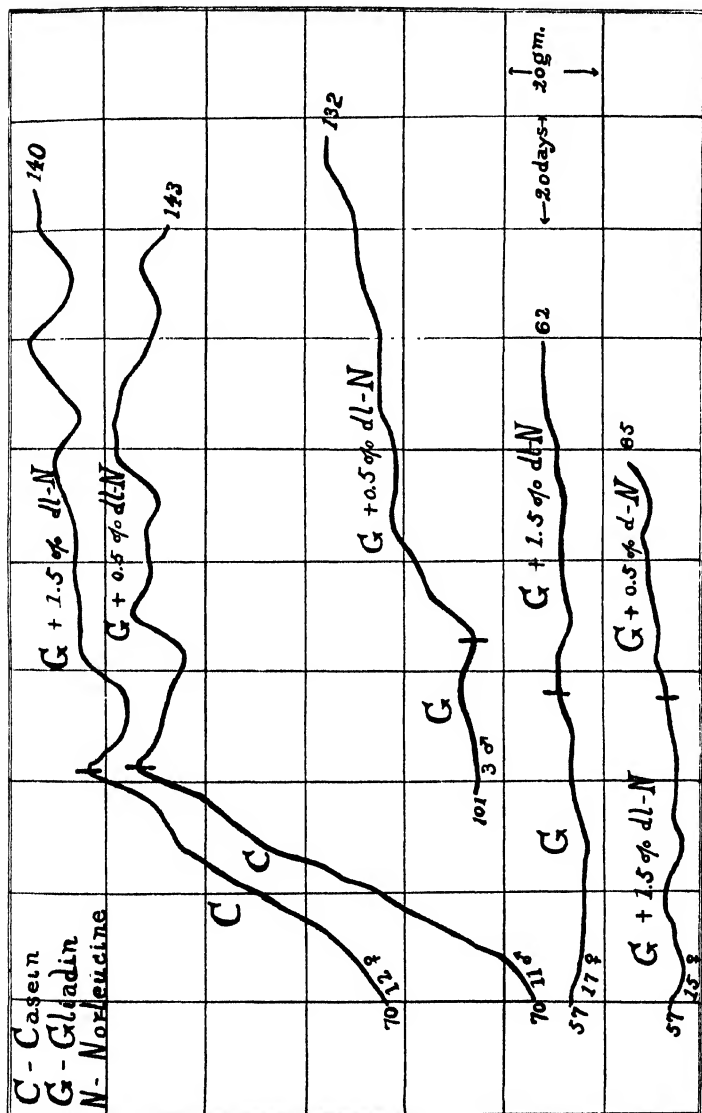


CHART 1. Showing the failure to grow normally when *dl*-nor-leucine supplements an 18 per cent gliadin diet. The curves for Rats 11 and 12 also show the prompt cessation of growth in older and larger rats when casein is replaced by gliadin and nor-leucine. In the case of Rat 15 no improvement results from the ingestion of the *d*-nor-leucine in place of the *dl* form.

lent to approximately 3 per cent of the protein of the above diet without further alteration renders the diet adequate for normal growth. These results are in agreement with those of Osborne and Mendel.

2. Neither *dl*- nor *d*-nor-leucine is able to supply the deficiency of a gliadin diet as does lysine. When nor-leucine is replaced by lysine in the experimental dietaries, normal growth ensues.

3. No evidence has been obtained which would indicate that nor-leucine is a precursor of lysine or that the organism of the white rat can substitute nor-leucine for lysine in the synthesis of its body protein for growth.

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EFFECT OF HYPODERMIC AND ORAL ADMINISTRATION OF CALCIUM SALTS ON THE CALCIUM CONTENT OF RABBIT BLOOD.

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Since the appearance of the work of Weiske (1), Forster (2), and Voit (3), who were among the first to realize clearly the importance of calcium for growth and maintenance, numerous attempts have been made to determine the various factors involved in the metabolism of this element. Although we know that it is possible, under certain dietary conditions, to cause an animal to store considerable amounts of calcium, no definite site of storage has been demonstrated. Weiske (1), Voit (3), Aron and Sebauser (4), Kost (5), Patterson (6), and Denis and Minot (7), experimenting with various animals on calcium-rich and calcium-poor diets, were unable to demonstrate any appreciable differences in the calcium content of the blood, bones, or tissues.

The experimental work¹ presented in this paper was carried out to ascertain if it is possible, by various means, to produce a definite increase in the calcium content of the circulating blood of different animals and, if so, whether the increase is permanent or transitory. The following methods were used in an attempt to increase the calcium content of the blood.

1. Intravenous and subcutaneous injections of calcium salts.
2. A calcium-rich diet.

Two groups of experiments were carried out to determine the effects of injected calcium salts. In the first, rabbits confined in metabolism cages were fed a diet of equal amounts of rolled

¹ This work was begun in 1917, with H. A. Mattill, Department of Nutrition, University of California, but was soon suspended and not taken up again until late in 1918.

TABLE I.

Effects of Intravenous and Subcutaneous Injections of Calcium Salts.

Day of experiment.	Ca per 100 cc. of whole blood.*	Remarks.	Weekly calcium.			
			In-gested.†	Eliminated.†		Balance.
				Urine.	Feces.	
Rabbit 1 ♀, weight 2,640 gm.						
	mg.		gm.	gm.	gm.	gm.
7	10.81					
10	10.10					
14	11.75	40 min. after intravenous injection of 63 mg. of Ca, as 1 per cent calcium chloride.	0.678	0.070	0.937	-0.329
14	9.87	130 min. after above injection.				
14	8.93	235 " " " "				
21	8.84	193 " " subcutaneous injection of 38 mg. of Ca, as saturated calcium hydroxide.	0.498	0.034	0.675	-0.211
29	9.12	5 min. after subcutaneous injection of 19 mg. of Ca, as saturated calcium hydroxide.	0.686	0.030	0.609	+0.047
Rabbit 2 ♀, weight 3,285 gm.						
10	13.58					
12	12.22					
14	13.16	75 min. after subcutaneous injection of 63 mg. of Ca, as 1 per cent calcium chloride.	0.248	0.230	0.363	-0.345
14	12.69	180 min. after above injection.				
21	11.84	15 " " subcutaneous injection of 38 mg. of Ca, as saturated calcium hydroxide.	0.391	0.181	0.335	-0.125
21	11.84	75 min. after above injection.				
21	11.00	260 " " " "				
29	12.31	7 " " subcutaneous injection of 17 mg. of Ca, as saturated calcium hydroxide.	0.579	0.203	0.834	-0.458
29	13.07	30 min. after above injection.				

* Calcium determinations made by author's method (unpublished work), which, with modifications, is the same as that outlined by Halverson and Bergeim (8).

† Calcium determinations in food, feces, and urine made by McCruden's (9) method.

barley and fresh carrots, practically a balanced ration with respect to its acid- and base-forming constituents.² After a normal period of 14 days the animals received weekly injections of calcium salts, in doses varying from 19 to 63 mg. of Ca. In the second group, the animals were fed a normal diet (alfalfa, barley, greens), and were given much larger injections, 200 to 250 mg. of Ca every 5th day. The results of these experiments, given in Tables I, II, and III, indicate a rapid elimination of the injected calcium. Although most of the calcium, 80 to 90 per

TABLE II

Effects of Intravenous and Subcutaneous Injections of Calcium Salts.

Rabbit 3 ♂, weight 3,263 gm.

Day of experiment.	Ca per 100 cc. of whole blood.*	Remarks.
	mg.	
7	10.78	
9	10.81	
11	9.40	
14	11.28	70 min. after the intravenous injection of 63 mg. of Ca, as 1 per cent calcium chloride.
14	8.93	185 min. after above injection.
14	8.93	315 " " " "
21	12.50	45 " " the subcutaneous injection of 50 mg. of Ca, as saturated calcium hydroxide.

* Calcium determinations made by author's method (unpublished work), which, with modifications, is the same as that outlined by Halverson and Bergeim (8).

cent, is rapidly eliminated, it is possible to obtain a definite but transitory increase in the calcium content of the blood, this being in agreement with the work of Heubner and Rona (11) who used a large number of cats as experimental animals and with that of von Fenyvessy and Freund (12) who used rabbits.

One rabbit was used as a control to determine the effects of frequent hemorrhage upon the calcium content of whole blood and plasma. Approximately the same amounts of blood were taken from this animal at time intervals corresponding to the

² According to data given by Sherman and Gettler (10).

removal of blood samples from the animals receiving injections of calcium salts. The results, given in Table IV, show that repeated hemorrhage causes a decrease, 10.7 to 12 per cent, in the calcium content of the plasma but only a slight and questionable change in the whole blood. The same effects are observed in the animals receiving the injections of calcium salts. Heubner

TABLE III.

Effects of Intravenous Injections of Calcium Chloride.

Day of experiment.	Hematocrit.*	Ca per 100 cc. of whole blood.†	Ca per 100 cc. of plasma.†	Remarks.
Rabbit 4 ♂, weight 3,636 gm.				
1	38.7	9.58	12.14	
4	39.5	10.15		
5	37.4	10.53	13.71	
5	33.1	10.53	14.56	120 min. after intravenous injection of 200 mg. of Ca, as 0.5 N calcium chloride.
5	33.4	9.71	12.99	195 min. after above injection.
10	30.9	10.68		
10	27.1	10.83	14.38	180 min. after intravenous injection of 250 mg. of Ca, as 0.5 N calcium chloride.
10	27.4	10.05	13.66	300 min. after above injection.
Rabbit 5 ♂, weight 3,523 gm.				
4	40.2	9.33	13.62	
5	36.3	8.81	12.95	
5	35.3	11.05	15.75	70 min. after intravenous injection of 200 mg. of Ca, as 0.5 N calcium chloride.
5	31.1	7.54	11.42	240 min. after above injection.
5	29.6	8.21	10.66	340 " " " "
10	31.8	9.63	13.37	
10	31.4	10.05	15.23	120 min. after intravenous injection of 250 mg. of Ca, as 0.5 N calcium chloride.
10	27.2	8.96	11.95	240 min. after above injection.
10	27.6	8.89	11.79	360 " " " "

* Hematocrit values obtained by centrifuging in capillary tubes for 10 min. at approximately 3,600 revolutions per min.

† Calcium determinations in whole blood and plasma made by author's (13) method of direct precipitation.

and Rona (11) report somewhat similar results but found that both plasma and whole blood gave normal calcium values by the end of the 7th hour. The data presented in this paper, contrary to the report of the above authors, does not show any tendency towards a return to normal at the end of the 5th or 6th hour.

The effects of a calcium-rich diet on the calcium content of the blood are given in Table V. The diet was a mixture of four parts of rolled barley and one part of alfalfa leaves containing 2 per cent of calcium lactate. The drinking water also contained 2 per

TABLE IV.
Effects of Frequent Hemorrhage on the Calcium Content of Whole Blood and Plasma.

Rabbit 6 ♂, weight 2,500 gm.

Day of experiment.	Hematocrit.*	Ca per 100 cc. of whole blood.†	Ca per 100 cc. of plasma.†	Remarks.
	<i>per cent</i>	<i>mg.</i>	<i>mg</i>	
4	36.6	9.78	12.84	
5	32.2	9.59	12.92	Blood sample at 10.50 a.m.
5	29.1	9.11	12.32	70 min. later.
5	30.9	9.11	11.27	250 " "
10	33.7	9.03	12.47	Blood sample at 9.30 a.m.
10	29.4	8.89	12.02	120 min. later.
10	29.1	8.66	12.32	240 " "
10	27.3	8.58	11.13	360 " "

* Hematocrit values obtained by centrifuging in capillary tubes for 10 min. at approximately 3,600 revolutions per min.

† Calcium determinations in whole blood and plasma made by author's (19) method of direct precipitation.

cent of calcium lactate. This was the only calcium salt that seemed at all acceptable to the animals and even this resulted in a much diminished food intake. The high calcium content of the alfalfa leaves (a composite sample gave 2.12 per cent Ca^3 on a dry basis), and the readiness with which they are ingested would indicate a more successful means of increasing the calcium intake. The results of these experiments show that it is not possible to increase the calcium content of rabbit blood by feeding a calcium-rich diet, which is in agreement with the recent work of

* Forbes (14) reports 2.14 per cent Ca in alfalfa leaves.

Denis and Minot (7) who carried out similar experiments with men, rabbits, and dogs. Goitein (15) and Voorhoeve (16) report definite increases in bone and blood calcium after the ingestion of a calcium-rich diet. The analytical methods used by the latter are of such a nature as to make the results of doubtful value.

TABLE V.

Effects of a Calcium-Rich Diet on the Calcium Content of Blood and Plasma.

Day of experiment.	Hema- toerit.	Ca per 100 cc. of plasma †	Ca per 100 cc. of whole blood †	Weekly calcium.			
				In- gested ‡	Eliminated.‡		Balance
					Urine.	Feces.	
Rabbit 7 ♂, weight 3,436 gm.							
	<i>per cent</i>	<i>mg.</i>	<i>mg.</i>	<i>gm</i>	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>
Control period.,							
1	31.1	12.93					
30	36.0	13.04					
41		11.55					
43	32.5	12.70					
47	35.0	12.29		3.76	1.12	0.93	+1.71
Calcium-rich diet.							
54	39.3	13.32	9.12	7.15	2.45	1.70	+3.00
61	35.4	12.71	9.00	2.94	1.54	1.97	-0.57
68	37.8	12.48	8.22	3.69	1.13	1.93	+0.63
75	38.6	12.62	9.00	4.17	1.33	2.24	+0.60
Rabbit 8 ♀, weight 3,710 gm.							
Control period.							
1	23.2	13.07					
11	35.4	12.21					
13	28.6	12.90					
17	30.8	11.10		4.69	1.29	1.40	+2.00
Calcium-rich diet.							
24	36.1	12.28	8.76	7.00	1.80	1.31	+3.89
31	27.1	12.76	9.65	3.16	1.07	2.50	-0.41
38	26.7	13.56	10.99	4.16	1.78	2.84	+0.54
45	25.5	12.43	10.20	5.27	1.94	3.14	+0.19

* Hematocrit values obtained by centrifuging in capillary tubes for 10 min. at approximately 3,600 revolutions per min.

† Calcium determinations in whole blood and plasma made by author's (13) method of direct precipitation.

‡ Calcium determinations in food, feces, and urine made by McCrudden's (9) method.

SUMMARY.

1. Intravenous or subcutaneous injections of calcium salts may cause a transitory increase in the calcium content of rabbit blood.

2. Feeding a calcium-rich diet has no effect on the calcium content of rabbit blood.

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TOXIC ACTION OF INGESTED LINSEED MEAL ON TROUT.*

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(From the Bureau of Fisheries, United States Department of Commerce, Washington.)

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Recently at a commercial hatchery in Rhode Island a peculiar disease broke out among brook trout of 1 and 2 years. The fish turned black and many of them became blind. Large numbers of them died. Just previous to death the affected fish would dart rapidly through the water, sometimes jumping entirely out of the water. After swimming nervously thus for a few seconds the fish would usually turn partly on the side and remain quiescent, as if dead, for an instant and would then resume its former unnaturally sluggish swimming. In most cases the fish would repeat this performance several times before finally succumbing. The superintendent was at a loss to explain the phenomenon but believed that the disease was connected in some way with the linseed meal, which formed part of a new food which the fish had been receiving for 6 or 7 weeks before the disease appeared. The same fish previously had been fed a mixture containing cotton-seed meal.

Several weeks after linseed meal had been removed from the food, the affected fish, which had survived the disease, were for the most part still jet black in color and blind. They were thinner than normal fish, their blindness obviously handicapping them in their search for food. The vital organs appeared to be in normal condition. Microscopic examination of sections of the skin near the lateral line and just below the dorsal fin showed that the diameters of the melanophores had increased to nearly three times those of normal brook trout, thus accounting for the change in color of these fish.

* Published by permission of the Commissioner of Fisheries.

There is present in most linseed meals a glucoside which is usually partially split up, by enzymes present in the meal, into primary decomposition products, among which is hydrocyanic acid. According to Dunstan and Henry (1903-04) phaseolunatin, as the glucoside is called by them, is a dextrose ether of acetone cyanhydrin.

The non-toxicity of most linseed meals is due in large measure to the fact that decomposition of the glucoside does not take place in the stomach, because the enzyme has been destroyed by the high temperature to which the seed is subjected during the expression of the oil (Henry and Auld, 1908).

Cotton-seed meal is used extensively as a stock food. It has, however, a toxic action on pigs. Withers and Carruth (1913) have isolated from cotton-seed meal a substance called gossypol to which they have ascribed the toxic properties of the meal.

There are thus present in cotton-seed meal and in most unheated linseed meals substances which are toxic for certain animals. As both these meals were fed to the trout at the Rhode Island hatchery, the cotton-seed meal being fed from March to July and the linseed meal from July to the early part of September, it was thought advisable to include them both in a study of the causes of the disease, although what evidence had already been adduced seemed to prove that the linseed meal was solely responsible for causing the outbreak.

The observations and experiments recorded below were made at the commercial hatchery in Rhode Island and at the United States Government hatchery in White Sulphur Springs, West Virginia. The linseed meal employed in the entire study is the same as that which was in use at the commercial hatchery at the time of the outbreak of disease.

Experiments at the Rhode Island Hatchery.

The main object of the preliminary experiments was to determine which of the two meals had brought on the disease. It was considered of interest in this connection also to observe the effect of ingested raw linseed oil upon trout and to study the relative merits of cereal-meat meal mixtures and fresh hog lungs as foods for trout.

Accordingly, five lots of fish, each consisting of 300 yearling trout averaging about 5.2 inches in length and 0.97 ounce in weight, were placed in parallel ponds supplied with spring water of about 42° F. from a common trough at the head ends of the ponds. The fish of one lot (No. 1) were fed a mixture of Red Dog flour, meat meal, and water as a control. The fish of Nos. 2, 3, and 4 received feeds which were prepared by adding linseed meal, raw linseed oil, and cotton-seed meal, respectively, to the control ration. The fish of the remaining lot were fed ground hog lungs. The trout were given all the food they would take, being fed two or three and quite often four times a day.

TABLE I.

Composition of the Foods Received by the Trout at the Rhode Island Hatchery.

Lot No.	Food received.					
	Moisture.	Ash.	Ether extract (fat, etc.).	Protein.	Crude fiber.	Nitrogen-free extract (carbohydrate, etc.).
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
1	43.2	3.7	4.3	27.3	2.6	18.9
2	43.9	3.5	3.7	24.3	3.0	21.6
3	42.4	3.4	5.5	25.6	2.1	21.0
4	42.6	3.5	3.8	24.5	4.6	21.0
5	80.58	1.10	2.3	16.1		

The chemical composition of the five foods is given in Table I. The vegetable-meat meal mixtures were compounded in the proportions given in Table II and were obtained in the shape of short cylindrical particles of a doughy consistency by forcing them through a perforated plate. The particles were dusted with flour to prevent them from sticking together.

Results of Feeding Experiments.

The feces of all the fish receiving the cereal-meat meal mixtures were different from those of the fish receiving the lungs. The excrement of the latter was long, stringy, and voluminous, while that of the former was granular, like soaked rice in appearance, and comparatively small in volume.

At the end of 30 days of feeding no difference in the size, color, actions, or condition could be noted in the fish of Nos. 1, 3, 4, and 5. However, the fish of No. 2 at this time were in poor

TABLE II.

Results of Feeding Experiments Performed at the Rhode Island Hatchery.

Beginning of experiment, Jan. 27, 1918; end of experiment, Apr. 22.

Lot No.	Weight of 300 yearling brook trout	Average weight of fish.	Food.	Food consumed.	No of dead fish.	Average weight of surviving fish.	Increase in weight.	Remarks.
		oz.		lbs.		oz.	per cent	
1	18 lbs. 4 oz.	0.97	16 parts Red Dog flour. 16 parts meat meal. 25 " water.	37.25	27	1.18	21.65	Appearance normal. Appetite good.
2	18 lbs. 2 oz.	0.97	11 parts Red Dog flour. 11 parts linseed meal. 11 parts meat meal. 25 " water.	Fair appetite during 1st week or 10 days only. Several turned black on Feb. 25. Food consumed to Mar. 8, 9.83 lbs. Dead fish to Mar. 8, 63. Many of the black fish appeared to have impaired vision.*				
3	18 lbs. 0.5 oz.	0.96	16 parts Red Dog flour. 16 parts meat meal 1 part linseed oil. 25 parts water.	39.67	63	1.26	31.25	Appearance fair. No black or blind fish.
4	18 lbs 3 oz.	0.97	11 parts Red Dog flour. 11 parts cotton-seed meal. 11 parts meat meal. 25 " water.	41.33	12	1.20	23.71	Appearance normal. No black or blind fish.
5	16 lbs. 10 oz.	0.89	Fresh hog lungs.	116.5	2	1.55	74.16	Appearance excellent.

* On Mar. 21 the surviving fish of this lot were divided into two groups. The fish of one group (65 trout) were fed ground fresh beef spleen and the fish of the other group (81 trout) continued to receive the same food as previously. On Apr. 22 there remained 50 fish of the former group, including 2 black and blind fish and but 14 fish of the latter group.

condition; several had turned black but were not blind as yet. Their action was sluggish for the most part and they seemed to have difficulty in maintaining equilibrium. Occasionally a fish would begin a nervous twisting and darting movement through the entire length of the pond, exciting other fish to similar actions. At the completion of the spasm, the fish would come to rest and roll onto one side for a moment as if exhausted. Although quite a large number of the fish in this lot turned black during the entire course of the experiment, at no time were there more than three or four of them present simultaneously, the fish dying soon after turning black. The results of the feeding experiments carried on at the Rhode Island hatchery are recorded in Table II.

As a result of the above experiments, the following points are made clear: (1) of the two vegetable meals, linseed and cottonseed, the linseed meal alone is responsible for causing the pigment change, blindness, and death; (2) the causative agent is contained in the non-oil constituents of the linseed meal; (3) linseed oil in the food of trout has a slightly injurious effect upon the fish; (4) fish affected with linseed meal poisoning can be brought back to a healthy condition, except for the pigment change and blindness, by a diet of some fresh meat product; (5) yearling trout during 3 months on a diet of hog lungs gained in weight three times as fast as those receiving the cereal-meat meal mixtures; however, a three times greater gross weight of food was consumed in the former case than in the latter.

Experiments at the Hatchery at White Sulphur Springs, West Virginia.

When it had been determined that the principal disease manifestations were due to the non-oil constituents of linseed meal, it remained to be shown what part was played by the cyanogenetic glucoside. As previously stated, the glucoside occurring in linseed meal is not poisonous as such, but is injurious after hydrolysis of the hydrocyanic acid formed. The remaining feeding experiments were performed for the purpose of ascertaining, if possible, to what extent the disease symptoms brought on by the linseed meal were the result of the action of hydrocyanic acid.

The proportion of materials entering into the composition of the rations fed to the trout in these experiments is given in Table III. On the basis of an analysis of the linseed meal constituent, Food B contained 0.0255 per cent of "free" hydrocyanic acid.¹ Foods E, F, G, and H were prepared by adding to the control ration (Food A) amounts of potassium cyanide which would bring their CN content equal to, one-fifth, triple, and five times that of Food B. Prior to its admixture with the other ingredients, the linseed meal of Food D was extracted with hot alcohol in a Soxhlet extractor for 24 hours to remove the glucoside and hydrocyanic acid (Auld 1911). Food C consisted of ground fresh hog lungs.

The manner of preparation of the foods containing vegetable and meat meals was the same as in the previous study. The small particles were thrown into the ponds in small amounts at a time and for the most part the fish devoured the food before it had an opportunity to sink to the bottom. There was little likelihood that the potassium cyanide in some of the foods was leached out before the food was swallowed by the fish.

Results of Feeding Experiments.

A. Influence of the Water.

The results of the experiments are recorded in Table III. Attention should first be called to the unusual rise in the mortality of the fish in Nos. 6, 9, 10, and 11a from September 3rd to October 1st. If the fish of No. 6 had not been among those which had an increased mortality, one might well have assumed that the deaths in the other groups were due in large measure to the action of the hydrocyanic acid. The high death rate of the fish of No. 6 could not have been due solely to the food as this same ration of Red Dog flour and meat meal proved to be fairly satisfactory when fed to trout at the Rhode Island hatchery.

¹ Method for the analysis of "free" hydrocyanic acid in linseed meal: About 250 cc. of water are placed in a round bottomed, long neck flask of about 1.5 liters capacity, a few drops of toluene added, and the liquid is brought to the experimental temperature by immersion in a thermostat. A weighed quantity of the finely ground cake, 25 to 50 gm. according to circumstances, is then introduced into the flask, mixed by giving the contents a shake, and the flask then stoppered with a rubber bung, and placed in the thermostat. When the action has ceased (12 hours at 38°C.) the contents of the flask are steam-distilled into saturated sodium bicarbonate solution and the prussic acid content of the distillate is determined by titration with 0.02 N iodine solution. The production of a faintly yellow color, due to excess iodine, indicates the end of the reaction (Auld, 1911).

The water in the hatchery at White Sulphur Springs contains at times a marked excess of dissolved gases. At such times any fish in the fry stage are seriously affected unless measures are taken to readjust the air content of the water to more nearly a normal level by some means of aeration. Fingerling and adult fish hitherto have never been affected by it. It is possible that the increased death rate of these experimental fish was due to this one factor, but it is more plausible to believe that their death was due in part to this cause and in part to the effect of the prolonged feeding with the "artificial" foods, for the fish which were receiving hog lungs (Lots 7a and 12) at this time suffered but slight losses. The fish of No. 8 which received the cereal-meat meal mixture containing linseed meal that had been thoroughly extracted with hot 95 per cent alcohol to remove the glucoside did not show a high death rate until 2 weeks after the increased mortality began to take place among the fish in Nos. 6, 9, 10, and 11a. That the fish in No. 8 did not begin to die 2 weeks earlier was probably due to the fact that these fish were in better condition at this time than the other fish receiving cereal-meat meal mixtures because they had not been receiving the artificial food mixture long enough to affect them seriously.

B. Fresh Hog Lungs Compared with a Food Prepared from Dried Meals.

The fish of No. 6, fed on a diet of Red Dog flour and meat meal, during the first period suffered about the same from deaths as did the fish of No. 12 which received ground hog lungs. During the second period, however, the average number of fish dying per week in No. 6 was 8.2 while that in No. 12 was only 0.6. It is doubtful whether the mortality of the fish of No. 6 would have been so high during the second period if it had not been for the added effect of an unfavorable condition of the water in the ponds, that may have prevailed at this time. The fish of this lot were undoubtedly in poorer condition during the latter part of the experiment than were the fish of No. 12. The increase in weight of the fish of No. 6 and No. 12 during the experiment amounted to 116 per cent and 129 per cent, respectively, the difference in favor of the fish receiving hog lungs not

Toxicity of Linseed Meal on Trout

TABLE III.
Results of Feeding Experiments Performed at Hatchery at White Sulphur Springs, West Virginia.

Lot No.	Food	Initial age No. initial weight of fish.	Deaths.																	Average weight of surviving fish.	Food consumed.	
			oz.	1st period, week ending				2nd period, week ending								Total.						
				July 16.	July 23.	July 30.	Aug. 6.	Aug. 13.	Average per week.	Aug. 20.	Aug. 27.	Sept. 3.	Sept. 10.	Sept. 17.	Sept. 24.		Oct. 1.	Average per week.				
6	A { Red Dog flour, Meat meal, Water,	oz. 8 8 8	100	1.18	3	0	1	1	0	1	3	0	0	2	8	13	24	8	8.2	63	2.55	19.17
7	B { Red Dog flour, Meat meal, Linseed meal, Water,	5.3 5.3 5.3 12	100	1.13	6	6	6	6	7	6.2									31	1.03	2.92	
7a Survivors of No. 7.)	C Fresh hog lings.		54								5	0	1	0	0	0	0	1	1	7	2.66	
8	D { Red Dog flour, Meat meal, Extracted linseed meal, Water,	5.3 5.3 5.3 12	51	1.68							0	1	0	0	1	7	8	2.4	17	1.89	5.67	

9	E	{ Red Dog flour, 8 Meat meal, 8 Water, 8 KCN, 0.0791 gm.	100	1.00	8	1	1	6	0	3.2	1	0	4	6	13	7	8	5.6	55	1.94	10.26
10	F	{ Red Dog flour, 8 Meat meal, 8 Water, 8 KCN, 0.0158 gm.	100	0.78	0	0	0	1	0	0.2	7	1	3	13	21	12	16	10.4	74	1.7	13.0
11	G	{ Red Dog flour, 8 Meat meal, 8 Water, 8 KCN, 0.2373 gm.	100	0.96	5	4	1	0	0	2.0								10	1.49	4.22	
11a (Survivors of No. 11.)	H	{ Red Dog flour, 8 Meat meal, 8 Water, 8 KCN, 0.3955 gm.	66	1.49						0	2	1	6	9	14	8	5.7	40	1.92	7.35	
12	C	Fresh hog lungs.	100	1.05	3	1	0	2	1	1.4	0	1	0	1	1	0	1	0.6	11	2.4	

being so marked as it was in the experiments performed at the Rhode Island hatchery. For some reason, possibly connected with the condition of the water and the somewhat apathetic attitude of the fish toward their food, the fish of No. 6 ate very little food during and after the week ending September 17th.

During the entire course of the experiment the fish of No. 6 appeared to be normal in health. No evidence of a pathological condition could be discerned. However, the ration which they received, consisting of equal weights of Red Dog flour, meat meal, and water, did not fulfill all the requirements of a good trout food. The fish receiving this ration, though they showed no apparent signs of ill health, suffered a somewhat higher mortality than the fish receiving the hog lungs. We must, therefore, conclude that, as a food for trout, such a mixture of flour and meat meal cannot be used to advantage to replace ground hog lungs or other fresh products of the packing house industry.

C. Effect of Ingested Linseed Meal on Trout.

During the entire 5 weeks of the feeding period from July 10th to August 13th, there was a weekly loss of about six fish in No. 7 receiving linseed meal (Food B). This loss was much greater than that which occurred in No. 9 which received an amount of potassium cyanide equivalent (molecularly) to the amount of hydrocyanic acid found by analysis in Food B. The greater toxicity of the linseed meal is probably ascribable to the action of linseed oil. It had earlier been determined that the linseed oil produces a slightly unfavorable influence on fish to which it is fed. It does not in itself cause the fish to turn black in color.

The fish of No. 7 began to act peculiarly within 8 days after the beginning of the feeding period. They darted hither and thither through the water occasionally. The nervousness of the fish was quite pronounced when they were disturbed by the sudden approach of someone to the edge of the pond. At such times some of the fish would jump out of the water in their excitement. They began to turn dark in color about 30 days after the experiment was started. Many of them at this time had sores on their snouts and fungus on their dorsal and adipose fins. Their appetite for Food B had fallen off also. After 35 days there

were two jet black fish among those surviving. Most of those which had died during the final days of the 5 weeks period were dark or black in color. The lower part of the intestines of nearly all the recently dead fish was very much inflamed. A like condition pertained in the living black fish.

The fish of No. 9 did not act peculiarly, that is, show signs of nervousness, until about 30 days after the feeding began. At this time they acted in a manner exactly similar to that of the fish of No. 7. There were no dark ones noted, however, until 40 to 45 days after the initial feeding, when many of the fish turned jet black in color. Furthermore, the lower part of the intestines of the affected fish was found to be congested with blood. After about 60 days the fish began to become infected with fungus.

The above observations would seem to prove that the pigment change and nervous condition were due primarily to the hydrocyanic acid of the linseed meal. The disease symptoms occurred much later in the fish of No. 9 than they did in those of No. 7. The belief that these symptoms were due entirely to the cyanide is strengthened by the fact that the fish of No. 6, receiving a ration identical in composition with that of Food E, except for the absence of potassium cyanide, did not give these manifestations. Furthermore, Food D, containing linseed meal from which the poisonous glucoside and the hydrocyanic acid had been removed by extraction with hot 95 per cent alcohol did not produce the pronounced "linseed meal" effect upon the fish of No. 8. The latter fish did become mildly nervous about 15 days after the initial feeding and were perhaps a little darker in color at the end of the experiment, though the color change was so slight as to make this observation of doubtful importance. The mortality of these latter fish was very low.

The fish of No. 7 at the end of 5 weeks were placed on a diet of ground hog lungs. The high mortality rate ceased almost at once and the fish somewhat regained their normal color. No totally blind fish were noted in this lot, as was observed in the case of the fish of No. 2 (Table II).

There is thus quite clear evidence that the outward manifestations of the disease, the pigment change and the excitability, produced in trout by the ingestion of linseed meal are due primarily to the hydrocyanic acid constituent of that food-stuff.

D. Effect upon Trout of Foods Containing Different Concentrations of Potassium Cyanide.

As previously stated, analysis showed that Food B contained 0.0255 per cent of "free" hydrocyanic acid, corresponding molecularly to 0.0614 per cent of potassium cyanide. If the figure 0.0614 is represented by a , then the proportions of potassium cyanide in Foods E, F, G, and H would correspond to a per cent, $\frac{a}{5}$ per cent, $3a$ per cent, and $5a$ per cent, respectively. Although during the first 7 or 8 weeks of the experiment the mortality of the fish receiving the rations containing potassium cyanide was a trifle higher than that of the control lot, the number of deaths during this time which might with certainty be attributed to the action of the cyanide is very small indeed. It happened that, during the latter half of the experiment, the greatest mortality occurred among the fish receiving the smallest amount of potassium cyanide (No. 10) and in this lot only were the number of deaths greater than in the control lot (No. 6). From these facts we are led to believe that the cyanide in the concentration and amount received by the trout had very little effect upon their mortality during the 12 weeks the fish were under observation.

The hydrocyanic acid of Foods E, F, G, and H did, however, produce disease symptoms in the fish. The food containing a per cent of potassium cyanide seemed to be more effective than the others in causing the fish to turn black and to get into an excitable state. Foods G and H, containing $3a$ per cent and $5a$ per cent of potassium cyanide, respectively, were a trifle less effective in this respect. Food F, containing $\frac{a}{5}$ per cent of potassium cyanide, was practically without any influence in this direction. It was noted that a number of the fish which had turned dark in color after having received for some time the foods containing either linseed meal or potassium cyanide were slightly defective in eyesight, quite a few being blind in one eye. It will also be recalled that a very large number of the black trout remaining in the preserves of the commercial hatchery after the management had stopped feeding linseed meal to the fish were totally blind.

The hydrocyanic acid present in the linseed meal, therefore, produces in trout partaking of a food consisting of equal parts by weight of Red Dog flour, meat meal, and linseed meal, a number of pronounced characteristic symptoms, among which are a nervous, excitable state, a change to a darker color or a jet black shade, and a weakened eyesight or blindness. However, the death of such fish appears to be due less to the action of the hydrocyanic acid than to some other factor. The possible cause for these effects will now be discussed.

Discussion of the Toxicity of Potassium Cyanide for Trout.

Pharmacologists state that prussic acid first stimulates then paralyzes the central nervous system in mammals. The lethal dose for man is about 0.05 to 0.08 gm. (Cushny, 1918). Assuming 145 or 150 pounds as the average weight of man, the lethal dose for man would be about 0.0003 to 0.0005 gm. per pound of body weight. The fish of No. 9 received an average of 1 gm. of food per fish per day for the first 21 days. They thus received an amount of potassium cyanide which corresponds molecularly to 0.00077 gm. of hydrocyanic acid per pound of fish per day. As the food was given to the fish twice daily and as some of the fish were more ravenous eaters than others, it is safe to say that many of these fish received as high as 0.0004 gm. of hydrocyanic acid, as potassium cyanide, per pound of body weight at one feeding. This proportion of acid to body weight in man, as above stated, is fatal. However, it did not appear to prove fatal to the fish. It caused many of them to turn black and blind and to act peculiarly. They seemed to be hypersensitive. Are all these symptoms related?

It is well known that certain fish possess the power of changing color to match the shade of their immediate background (Mast, 1914, and Bray, 1918). These colors are produced by concentration and dispersion of the pigment granules in the chromatophores of the skin. The movement of the granules is under the control of stimuli received through the eye, by way of the central and sympathetic nervous systems. When the eyesight of these fish is destroyed they can no longer simulate the background.

Blind trout are usually dark in color, often jet black. When a trout is blind in one eye, the opposite side will be black while the near side will be unchanged (Arens, 1904).

It appears that in trout as in other fish the stimuli received through the eyes are responsible for the adaptive changes in shade and then when vision is impaired the fish become dark in color or black. The amount of hydrocyanic acid received by the trout in these experiments, though not sufficient to kill the fish, apparently was large enough to produce a mild effect upon the central nervous system, causing the fish to become alternately hypersensitive and apathetic. It is the opinion of the authors that impaired vision caused the fish to turn dark in color. If the action of the acid was not too prolonged the fish resumed their natural color after a period of feeding on a cyanide-free ration.

SUMMARY.

1. Brook trout receiving a food mixture consisting of equal weights of Red Dog flour and meat meal did not gain in weight so fast as trout receiving fresh hog lungs, and the latter fish, after several weeks feeding, possessed a greater vitality or reserve strength than the former. Such a mixture is not an adequate substitute for the fresh, packing house products ordinarily used as food for trout.

2. Ingested raw linseed oil is slightly toxic to brook trout.

3. Ingested linseed meal produces in brook trout a nervous, excitable state, causes them to become black and blind, and proves fatal to a large proportion of the fish.

4. The injurious effect of ingested linseed meal upon brook trout is due in large measure to hydrocyanic acid which is present in most linseed meals as the result of the hydrolysis of a cyanogenetic glucoside. The amount of hydrocyanic acid ingested in the linseed meal at any given time was insufficient to produce death.

5. The nervousness, pigment change, and blindness are all believed to be referable to the action of the hydrocyanic acid on the nervous system of the trout. The observations reported herewith indicate that this action results in an impairment of the vision and a consequent interference with the control of the

movement of the pigment granules in the chromatophores of the skin, this control normally being obtained by means of stimuli received through the eyes by way of the central and sympathetic nervous systems.

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A STUDY OF THE ANTISCORBUTIC VALUE OF HONEY.

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The recent paper of Dutcher¹ showing that honey contains a small amount of antineuritic vitamine (probably due to included pollens rather than to the soluble constituents) naturally raises the question whether honey contains other vitamins as well. No investigation regarding antiscorbutic vitamine in honey has appeared and it was to throw light on this point that the present study was made.

A series of ten guinea pigs was fed on a diet of oats and water, which is known to produce scurvy in guinea pigs, and in addition white sage, comb honey bought in the open market and extracted from the comb on the day of administration was offered. In a preliminary period of from 5 to 6 days (Animals 1 to 6) it was found that undiluted honey was refused. A watery solution, one part of honey to fifteen parts of water, was accepted. This was administered for a period of 13 days. The strength was then increased to two parts of honey to fifteen parts of water. In the case of Animals 7 to 10 of the series, the 2:15 mixture was administered from the beginning up to the 21st day, when a 1:5 mixture was offered and taken. Daily inspection of the animals was made for tenderness of the joints, general behavior, and appearance of "face ache" position. The animals were weighed every 3 days. Though all the guinea pigs showed a progressive loss of weight, none, excepting No. 6, showed clinical evidence of scurvy until the 4th or 5th week. Marked tenderness of the knees was noted only in No. 6. This animal beginning on the 26th day behaved in a peculiar manner. When examined in the morning he was found lying on his back. When the knees were

¹ Dutcher, R. A., *J. Biol. Chem.*, 1918, xxxvi, 551.

TABLE I.

Effect on Guinea Pigs of Diet of Oats, Water, and Honey.

Animal No.	Initial weight.		Lived.	Final weight.	Died or killed.	Honey.		Scurvy.	Remarks.
	gm.	days				Total intake.	Average daily intake.		
	gm.	days	gm.			cc.	cc.		
1	525	42	300	Died.		190.4	6.03	++	Refused honey first 5 days. Honey intake measured last 30 days only. Teeth loose. Ribs: hemorrhage; ends enlarged; white line.* Hemorrhage of cecum and colon. Hemorrhage of right femur.
2	500	37	375	"		163.5	5.85	+++	Refused honey first 5 days. Honey intake measured last 28 days only. All teeth loose, cutting edges worn and black. Ribs: ends enlarged; white line; many hemorrhages. Large swellings and hemorrhages of both knees.
3	525	40	325	"		199.2	8.30	++	Refused honey first 5 days. Honey intake measured last 24 days only. Teeth loose. Ribs: ends enlarged; white line; several hemorrhages. Hemorrhage of one knee.
4	575	38	350	"		160.6	5.04	+	Refused honey first 6 days. Honey intake measured last 30 days only. Teeth slightly loose. Ribs: white line; 2 hemorrhages; no enlargements. Mandible much thinned.

* This "white line" is a macroscopic chalky white band of necrotic bone running transversely across the end of the rib at or near the cartilaginous junction, and probably corresponds with the radiographic "white line" found at the ends of the diaphyses of the long bones in human cases of scurvy. In guinea pigs with scurvy the costal white line is strikingly constant and is probably pathognomic of the disease.

TABLE I—*Concluded.*

Animal No.	Initial weight		Lived.	Final weight	Died or killed.	Honey.		Scurvy.	Remarks.
	gm.	days		gm.		Total intake.	Average daily intake.		
						cc.	cc.		
5	200	35		150	Died	137.9	5.31	+	Refused honey first 6 days. Honey intake measured last 26 days only. Teeth loose; alveolar hemorrhage. Ribs: few epiphyses enlarged. Hemorrhage in marrow of one femur.
6	200	27		175	Killed.	71.9	3.99	(?)	Refused honey first 6 days. Honey intake measured last 18 days only. Killed because of squealing when knees were pinched; weakness, etc. No gross lesions of scurvy. No microscopic examination.
7	200	26		130	Died.	214.4	8.25	++	Teeth loose. Ribs: ends enlarged; white line; several shafts fractured. Extensive hemorrhage of thoracic wall, left side. Hemorrhage of patellar ligament.
8	150	26		100	"	218.0	8.38	++	Teeth loose. Ribs: few small hemorrhages; ends enlarged; white line. Knees swollen and hemorrhagic.
9	210	26		150	"	161.4	6.21	++	Teeth loose. Ribs: several enlarged epiphyses; white line. Large recent hemorrhage of one knee; small hemorrhage of right knee. Subperiosteal hemorrhage of one femur.
10	150	30		125	"	191.8	6.39	+	Teeth not loose. Ribs: epiphyses enlarged; white line. Fresh hemorrhage of one knee.

pinched he squealed vigorously and when placed on his feet he moved about the cage in circles with an unsteady gait. The next morning he appeared to be normal but the following afternoon the peculiar symptoms reappeared. He was then killed but no characteristic gross lesions of scurvy were found. Through an unfortunate accident specimens for microscopic examination were not saved. It is quite possible that incipient scurvy, as suggested by the tenderness of the knees, was present. All the other animals died between the 27th and 42nd days and showed the characteristic lesions of scurvy, mostly of a recent and severe type.

The average daily intake of honey was between 3.99 and 8.30 cc. and between 0.88 and 5.58 cc. per 100 gm. of initial body weight. The degree of severity of the lesions was apparently unrelated to the amount of honey ingested.

It was at first thought because of the failure of scorbutic symptoms to develop until the 30th day in the six animals first tested that there was some evidence of protection against scurvy, since most animals fed on oats and water alone show signs of scurvy before this time.² The almost simultaneous appearance of severe scurvy in five of the six guinea pigs of the first set after the 30th day and in all of the last four at a still earlier period made such an assumption impossible. There seems to be no evidence that honey, at least in the quantities which guinea pigs can be induced to take, has any antiscorbutic value.

CONCLUSIONS.

1. In nine out of a series of ten guinea pigs fed on a diet of oats, water, and honey, severe scurvy developed in 4 to 6 weeks.
2. It is probable that no antiscorbutic vitamine is present in honey.

² Holst, A., and Frölich, T., *Z. Hyg.*, 1912, lxxii, 1.

SYNTHESIS OF PHYTIC ACID.

FIFTEENTH PAPER.

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(Received for publication, June 7, 1920.)

INTRODUCTION.

Several attempts to synthesize phytic acid or inosite hexaphosphoric acid have been described in recent years. The methods have varied slightly but the principle in every experiment has been to obtain the desired product by heating together inosite and orthophosphoric acid.

Contardi¹ claimed to have synthesized phytic acid in this way and described his product as identical with the natural phytic acid isolated from plant material. Carré² was unable to substantiate the results of Contardi. Jegorow³ using a similar method obtained a substance containing organic phosphorus. The writer⁴ showed several years ago that inosite tetrphosphoric acid could be formed by heating inosite and phosphoric acid to 140–160°C. under reduced pressure.

Posternak⁵ claimed recently to have synthesized phytic acid by heating a mixture of inosite, phosphoric acid, and phosphorus pentoxide. He states that the synthetic phytic acid was isolated as a crystalline double calcium-sodium salt which after drying at 120° had the composition $C_6H_{12}O_{27}P_6Ca_2Na_8$. The analytical data are not given, but a comparative study of the crystallography of the natural and the synthetic salts is described. Posternak calls this acid "inosite hexaphosphoric acid" but he represents it by the formula $C_6H_{24}O_{27}P_6$. This formula differs from

¹ Contardi, A., *Atti r. Accad. Lincei rendic.*, 1909, xviii, series 5, 64.

² Carré, P., *Bull. Soc. chim.*, 1911, ix, 195.

³ Jegorow, M. A., *Biochem. Z.*, 1914, lxi, 41.

⁴ Anderson, R. J., *J. Biol. Chem.*, 1912, xi, 471.

⁵ Posternak, S., *Compt. rend. Acad.*, 1919, clxix, 138.

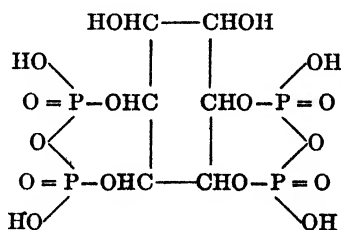
that of inosite hexaphosphoric acid, $C_6H_{18}O_{24}P_6$, by containing 3 molecules more of H_2O . How or in what manner these extra molecules of water are combined is not stated.

As a result of his earlier experiments to synthesize phytic acid by heating inosite and phosphoric acid, which only resulted in the formation of inosite tetrphosphoric acid; and in view of the fact that phytic acid always decomposes when heated into mixtures of inorganic phosphoric acid and lower inosite phosphoric acids, the writer was led to express the opinion⁶ that phytic acid could never be synthesized by heating together inosite and phosphoric acid.

Since the method adopted by Posternak differed from those discussed above only by the introduction of phosphorus pentoxide, it appeared of interest to repeat his work. Accordingly the reaction between inosite and a mixture of phosphoric acid and phosphorus pentoxide has been studied. The conditions of the reaction as described by Posternak were followed closely.

From the reaction mixture was isolated an inosite phosphoric acid which was not identical in composition with the natural phytic acid although it had very nearly the same percentage of phosphorus. The substance differed not only in composition from phytic acid but its properties and reactions with reagents also differed from those of phytic acid in several particulars.

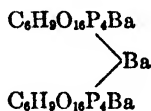
The composition of this new inosite phosphoric acid, as determined by the analyses of the barium and the silver salt, and of the free acid itself, agrees with the formula, $C_6H_{12}O_{16}P_4$. This corresponds to inosite dipyrophosphoric acid in which two hydroxyls of each molecule of the pyrophosphoric acid have reacted with two alcoholic hydroxyls of the inosite as indicated in the formula.



⁶ Anderson, R. J., Thesis, Cornell University, 1919, 19.

It is not possible to state, however, whether the constitution of the acid is accurately indicated by this formula, for the inosite may possibly be combined with a more condensed phosphoric acid.

The barium salt of this new acid corresponds to the formula $C_{12}H_{18}O_{32}P_8Ba_3$. Such a substance is either a mixture of the mono- and dibarium salts or else 2 molecules of the monobarium salt are united by 1 atom of barium.



The silver salt is precipitated from a slightly acid solution, on addition of silver nitrate, as a white amorphous precipitate which corresponds to the tetrasilver salt, $C_6H_8O_{16}P_4Ag_4$.

EXPERIMENTAL.

First Synthesis.

Dry orthophosphoric acid, 56 gm., was heated in a flask to 100° , and 12 gm. of dry inosite were added. The inosite was dissolved by continuing the heat between 100 – 110° . To this solution were added 90 gm. of phosphorus pentoxide in small portions. A very considerable increase in the temperature was observed when the phosphorus pentoxide was added. The mixture was well stirred by shaking and, finally, by a glass spatula. The flask containing the reaction mixture was then heated in an oil bath to 120 – 130° for 3 hours. It was cooled to room temperature, about 200 cc. of water were added, and the mixture of acids was dissolved by adding a 20 per cent solution of sodium hydroxide until the reaction was faintly alkaline to litmus. The solution was then filtered and concentrated on the water bath and set aside to allow sodium phosphate, pyrophosphate, etc., to crystallize.

The crystals were filtered off on a Buchner funnel and washed with several small portions of cold water. The filtrate was made up to 500 cc. with water, 25 gm. of sulfuric acid were added, and the solution was heated to 100° for 1 hour, for the purpose of

converting any pyrophosphoric acid into orthophosphoric acid. It has been shown by Plimmer⁷ that phytin is not appreciably hydrolyzed by such treatment. Sodium hydroxide was then added until the reaction was only faintly acid.

The organic and the inorganic phosphoric acids which were present in the solution were then precipitated by adding a concentrated solution of copper acetate in excess. The copper precipitate was filtered on a Buchner funnel and washed until free from sulfates; then it was suspended in water and decomposed with hydrogen sulfide. The copper sulfide was filtered off and the excess of hydrogen sulfide removed by a current of air. To the filtrate, about 5 liters, were added 400 gm. of barium chloride, resulting in a heavy white amorphous or granular precipitate. This precipitate was filtered and washed with water until free from chlorides. The addition of an equal volume of alcohol to the filtrate produced a voluminous white precipitate which was purified as will be described later.

Purification of the Substance Precipitated by Barium Chloride.

The moist precipitate was rubbed up to a thin paste with water and brought into solution by adding dilute hydrochloric acid drop by drop. It was then filtered and precipitated by adding a solution of barium hydroxide. The barium salt was filtered and washed free of chlorides with water and again dissolved in dilute hydrochloric acid, filtered, and precipitated by adding an equal volume of 95 per cent alcohol. The above mentioned alternate precipitations with barium hydroxide and alcohol from dilute hydrochloric acid were repeated four times. The substance was further precipitated twice with alcohol from dilute hydrochloric acid, finally washed with dilute alcohol and alcohol and ether, and dried in vacuum over sulfuric acid. It was a snow-white amorphous powder and weighed 7.3 gm.

Various attempts were made to crystallize this barium salt by the method formerly used in purifying barium phytate,⁸ but without success. The amorphous salt was free from chlorides and inorganic phosphate and it did not contain any weighable

⁷ Plimmer, R. H. A., *Biochem. J.*, 1913, vii, 72.

⁸ Anderson, R. J., *J. Biol. Chem.*, 1914, xvii, 141, 151, 165, 171.

quantity of sodium. When dissolved in dilute nitric acid it gave a pure white flocculent precipitate with ammonium molybdate. In strong solutions this precipitate appears immediately while in very dilute solutions it comes down only on warming. The precipitate remains pure white in color and does not turn yellow on warming to 65° or on standing at room temperature for a long time. Before the inorganic phosphate had been removed by the repeated precipitation of the barium salt by alcohol from dilute hydrochloric acid, the white precipitate produced by the ammonium molybdate assumed a yellow color either immediately or very gradually, depending upon the amount of inorganic phosphate which was present.

The substance was analyzed after drying at 105° in vacuum over phosphorus pentoxide.

0.2980 gm. substance gave 0.0427 gm. H_2O and 0.1121 gm. CO_2 .

0.1577 " " " 0.0861 gm. $BaSO_4$ and 0.1018 gm. $Mg_3P_2O_7$.

Found: C=10.26; H=1.60; P=17.99; Ba=32.12 per cent.

For $C_{12}H_{18}O_{12}P_3Ba_3$, 1,334, calculated: C=10.79; H=1.34; P=18.59; Ba=30.88 per cent.

Deducting the amount of barium found and allowing for its equivalent as hydrogen and water the composition of the free acid was calculated as follows.

C = 15.01; H = 3.03; P = 26.34 per cent.

For $C_6H_{12}O_{12}P_4$ = 464, calculated: C = 15.51; H = 2.58; P = 26.72 per cent.

Examination of the Substance Precipitated by Alcohol.

The white amorphous precipitate obtained by the addition of alcohol to the filtrate from the above barium salt was purified by precipitating it alternately fifteen times with barium hydroxide and alcohol from dilute hydrochloric acid in the manner described above. The snow-white amorphous product finally obtained gave in nitric acid solution a voluminous white precipitate with ammonium molybdate which gradually turned yellow on warming, thus showing the presence of inorganic phosphate. The substance was then dissolved in 200 cc. of very dilute hydrochloric acid and precipitated by adding 200 cc. of a saturated

solution of barium chloride. The heavy white precipitate which separated was filtered, washed, and again precipitated several times from dilute hydrochloric acid by alcohol. After finally filtering, the substance was washed free from chlorides with dilute alcohol and then washed in alcohol and ether and dried in vacuum over sulfuric acid. The snow-white product weighed 4 gm. Dissolved in dilute nitric acid it gave a voluminous pure white precipitate with ammonium molybdate which did not turn yellow on heating. The inorganic phosphate had, therefore, been removed completely.

The substance was analyzed after drying at 105° in vacuum over phosphorus pentoxide.

0.3343 gm. substance gave 0.0399 gm. H_2O and 0.1031 gm. CO_2 .
0.1768 " " " 0.1058 gm. $BaSO_4$ and 0.1135 gm. $Mg_2P_2O_7$.
Found: C=8.41; H=1.33; P=17.89; Ba=35.21 per cent.
Calculated to free acid: C=12.88; H=2.83; P=27.41 per cent.

The composition differs considerably from that of the first preparation obtained by precipitating with barium chloride, the percentage of carbon being lower and that of phosphorus higher. The composition approaches that of phytin or inosite hexaphosphoric acid, but its properties differ from those of phytin in that it is precipitated from dilute hydrochloric acid solutions by barium chloride and, also, in that its solution in dilute nitric acid gives a white amorphous precipitate with ammonium molybdate. Further, it was not possible to obtain any crystalline barium salts by the method used with barium phytates. Another difference in behavior was noticed in that the addition of water to the dilute hydrochloric acid solution of the barium salt gave a white precipitate.

This substance was probably a mixture of inosite phosphoric acids, but the nature of these esters could not be determined.

Second Synthesis.

Since in the first experiment no evidence had been obtained of the formation of phytic acid or inosite hexaphosphoric acid, it was decided to study the reaction between inosite, orthophosphoric acid, and phosphorus pentoxide under conditions varying

from that described above. A second synthesis was therefore carried out as follows:

Inosite, 9 gm., dry phosphoric acid, 39 gm., and phosphorus pentoxide, 39 gm., were mixed and heated in a flask exactly as described before except that the temperature of the oil bath did not exceed 120° and the mixture was heated for only 1 hour. The reaction mixture was worked up exactly as previously described and the substance precipitated by barium chloride was purified in the same manner as the first preparation by precipitating alternately with barium hydroxide and alcohol from dilute hydrochloric acid until the dilute nitric acid solution gave a pure white precipitate with ammonium molybdate. The product thus prepared was a snow-white powder which weighed 6.8 gm. after drying in vacuum over sulfuric acid. It was free from chlorides and inorganic phosphate and did not contain any bases other than barium.

The substance was analyzed after drying at 110° in vacuum over phosphorus pentoxide.

0.3993 gm. substance gave 0.0558 gm. H_2O and 0.1548 gm. CO_2 .
0.1835 " " " 0.0938 gm. $BaSO_4$ and 0.1220 gm. $Mg_2P_2O_7$.
Found: C=10.57; H=1.56; P=18.53; Ba=30.08 per cent.
Calculated to free acid: C=15.03; H=2.83; P=26.34 per cent.

Judging by the analytical result this product is evidently identical with the one obtained in the first synthesis.

Third Synthesis.

In a third experiment 9 gm. of inosite, 39 gm. of dry phosphoric acid, and 39 gm. of phosphorus pentoxide were heated for 1 hour in an oil bath having a temperature of 115 – 120° . The reaction product was isolated in the same manner as before. The substance after drying in vacuum over sulfuric acid weighed 11.7 gm. It was free from chlorides and inorganic phosphate, and bases other than barium were absent.

For analysis the substance was dried in vacuum at 105° over phosphorus pentoxide.

0.3543 gm. substance gave 0.0535 gm. H_2O and 0.1419 gm. CO_2 .

0.1891 " " " 0.0913 gm. $BaSO_4$ and 0.1270 gm. $Mg_2P_2O_7$.

Found: C=10.92; H=1.68; P=18.72; Ba=28.41 per cent.

Calculated to free acid: C=15.17; H=2.90; P=25.99 per cent.

The percentage of barium varied in these different preparations yet when the barium is deducted, allowing for corresponding quantities of hydrogen and water, fairly concordant results are obtained for the composition of the acid. These analytical results as shown below agree with an acid having the composition $C_6H_{12}O_{16}P_4$.

For $C_6H_{12}O_{16}P_4$ calculated . . . C=15.51; H=2.58; P=26.72 per cent.

Found first synthesis C=15.01; H=3.03; P=26.34 " "

" second " C=15.03; H=2.83; P=26.34 " "

" third " C=15.17; H=2.90; P=25.99 " "

Purification of the Barium Salt.

In the hope of obtaining a homogeneous crystalline salt of this acid the following experiment was made. The three barium precipitates of identical composition obtained by precipitating with barium chloride were united. The mixture weighed 22.8 gm. It was rubbed up to a fine thin paste with 200 cc. of water and brought into solution by adding just sufficient dilute hydrochloric acid. The solution was filtered and to it was added slowly and with constant shaking a concentrated solution of 11 gm. of barium chloride. The precipitate which formed at first dissolved on shaking and warming the mixture to about 65° . After adding all the barium chloride a slight permanent cloudiness remained which did not clear up on warming. The solution was then allowed to cool and to stand at room temperature over night. A heavy white powder separated gradually. This substance was not crystalline but it consisted, as shown under the microscope, of uniform transparent granules or globular particles.

This substance was filtered off, washed with water and then with alcohol and ether, and allowed to dry in the air. The snow-white powder weighed 3.1 gm. In nitric acid solution it gave no reaction with silver nitrate, and ammonium molybdate produced a voluminous pure white precipitate indicating that it was free from chlorides and inorganic phosphate. To the filtrate from

this preparation was added a concentrated solution of 20 gm. of barium chloride in the same manner as before until a faint permanent cloudiness remained. After standing over night a further quantity of the globular precipitate had separated which, under the microscope, appeared to be identical with the first preparation. This was filtered off, washed and dried as before, and was also found to be free from chlorides and inorganic phosphate.

These preparations were analyzed after drying to constant weight at 105° in vacuum over phosphorus pentoxide.

The first globular preparation gave the following results on analysis.

0.3784 gm. substance lost 0.0536 gm. on drying.

0.1813 " " " 0.0257 " " "

0.3248 " " gave 0.0463 gm. H_2O and 0.1267 gm. CO_2 .

0.1476 " " " 0.0757 gm. BaSO_4 and 0.0986 gm. $\text{Mg}_2\text{P}_2\text{O}_7$.

Found: C=10.63; H=1.59; P=18.62; Ba=30.18; H_2O = 14.16 per cent.

For $\text{C}_{12}\text{H}_{18}\text{O}_{32}\text{P}_8\text{Ba}_3 = 1,334$, calculated: C=10.79; H=1.34; P=18.59; Ba=30.88 per cent.

For 12 H_2O , calculated: 13.93 per cent.

The second preparation gave the following results.

0.2834 gm. substance gave 0.0382 gm. H_2O and 0.1050 gm. CO_2 .

0.1887 " " " 0.1062 gm. BaSO_4 and 0.1224 gm. $\text{Mg}_2\text{P}_2\text{O}_7$.

On drying it lost 14.61 and 14.51 per cent of water.

Found: C=10.10; H=1.50; P=18.08; Ba=33.12 per cent.

In these preparations the percentage of barium again varies, but on deducting the amount of barium found and allowing for a corresponding quantity of hydrogen and water the following results are obtained.

First globular precipitate... C=15.14; H=2.88; P=26.30 per cent.

Second " " ... C=15.01 H=2.92; P=26.84 " "

Calculated for $\text{C}_6\text{H}_{12}\text{O}_{16}\text{P}_4$. .C=15.51; H=2.58; P=26.72 " "

Preparation of the Acid.

The free acid was prepared from 3 gm. of the globular salt. The barium was removed with a slight excess of sulfuric acid and the barium sulfate filtered off. The filtrate was precipitated with an excess of copper acetate, filtered, and washed free of sul-

fates. The copper salt was decomposed in aqueous suspension by hydrogen sulfide. The copper sulfide formed an exceedingly persistent colloidal solution which it was very difficult to break up and so much time was consumed in this operation that some hydrolysis of the acid occurred, as shown by the fact that its dilute solution gave a white precipitate with ammonium molybdate which gradually turned yellow in color. Equally poor success was experienced with a second preparation of the free acid in which lead was substituted for copper. After the copper sulfide had finally been removed the solution was concentrated under reduced pressure at a temperature not exceeding 40° and then dried in vacuum over sulfuric acid. The acid was obtained as a colorless thick syrup which quickly dried forming a hard brittle mass. It was readily soluble in water and alcohol and it showed no tendency whatever to crystallize. The addition of ether to the alcoholic solution of the acid caused it to separate as small oily drops.

The acid was analyzed after drying to constant weight in vacuum at 78° over phosphorus pentoxide. On drying at this temperature the acid darkened slightly in color indicating some decomposition.

0.1464 gm. substance gave 0.0379 gm. H_2O and 0.0813 gm. CO_2 .

0.1588 " " " 0.1480 gm. $Mg_3P_2O_7$.

Found: C=15.15; H=2.89; P=25.97 per cent.

0.1565 gm. of the dry acid dissolved in 50 cc. of water required 15.4 cc. of 0.1 N NaOH using phenolphthalein as indicator.

For $C_6H_8O_5 [P_2O_5(OH)_2]_2$, calculated: 13.5 cc. of 0.1 N NaOH.

After titrating the above, an excess of neutral barium chloride was added which caused a white precipitate of the barium salt and at the same time an increase in the acidity which required 5.9 cc. of 0.1 N NaOH for neutralization. If we assume that the two free alcoholic hydroxyls in the inosite ring became acidic by reason of the presence of the adjacent acid molecules a hexa-basic acid would then be formed. For $C_6H_6(OH)_2O_4 [P_2O_5(OH)_2]_2$, calculated: 20.2 cc. of 0.1 N NaOH. As will be noticed, an excess of alkali was required but this was probably due to the slight hydrolysis of the acid during the preparation, of which mention has been made.

Properties of the Free Acid.

The aqueous solution of the acid gave white amorphous precipitates on adding silver nitrate, barium chloride, or calcium chloride. Magnesium chloride gave no precipitate in the cold but on warming a white precipitate was formed which redissolved on cooling. Copper sulfate in excess gave a bluish white precipitate. Ferric chloride gave a yellowish white precipitate which was very insoluble in hydrochloric acid. A dilute solution of the acid immediately precipitated egg albumin. As stated before ammonium molybdate produced, even in dilute solutions, a white flocculent precipitate either immediately or on warming; this precipitate, owing apparently to partial hydrolysis of the acid during its preparation, gradually turned yellow in color when the solution was warmed.

Phytic acid is not precipitated from aqueous solutions by barium or calcium chlorides. Ammonium molybdate produces a white granular or crystalline precipitate with phytic acid only in concentrated solution.

Preparation of the Silver Salt.

An aqueous solution of the acid was nearly neutralized with ammonia and then acidified by adding a few drops of nitric acid. Silver nitrate was added in slight excess and the white amorphous precipitate was filtered, washed in water and alcohol and ether, and dried in vacuum over sulfuric acid. The resulting silver salt was a nearly white amorphous substance which was very slightly sensitive to light and on moist litmus paper it showed only a faint acid reaction.

The salt was analyzed after drying at 105° in vacuum over phosphorus pentoxide.

0.2584 gm. substance gave 0.0257 gm. H_2O and 0.0773 gm. CO_2 .

0.2359 " " " 0.1497 gm. $AgCl$ and 0.1156 gm. $Mg_2P_2O_7$.

Found: C=8.15; H=1.11; P=13.66; Ag=47.76 per cent.

For $C_6H_8O_{16}P_4Ag_4$, calculated: C=8.07; H=0.89; P=13.91; Ag=48.40 per cent.

Hydrolysis of the Synthetic Preparation into Inosite and Phosphoric Acid.

The barium salt was hydrolyzed by heating in an autoclave to 140–150° for 2½ hours with dilute sulfuric acid. After cooling, the inosite was isolated in the usual way and recrystallized several times from water with the addition of alcohol. The quantity of pure recrystallized inosite which was obtained corresponded to 84 per cent of the theoretical amount. The substance gave the reaction of Scherer and melted at 223° (uncorrected). That it was pure inosite was shown by its crystal form, melting point, and the Scherer reaction, and analysis was therefore omitted.

SUMMARY.

A study has been made of the reaction between inosite, phosphoric acid, and phosphorus pentoxide.

The conclusion of Posternak that the organic phosphoric acid produced in this reaction is identical with the natural phytic acid or inosite hexaphosphoric acid, $C_6H_{18}O_{24}P_6$, or as formulated by Posternak, $C_6H_{24}O_{27}P_6$, could not be confirmed.

The only product which could be isolated in approximate purity from the reaction mixture corresponded to an inosite ester of pyrophosphoric acid containing 4 atoms of phosphorus or 2 molecules of pyrophosphoric acid. Traces of other inosite phosphoric acids are undoubtedly formed but the above substance represents the principal product of the reaction.

This new acid corresponds to the formula, $C_6H_{12}O_{16}P_4$. It resembles phytic acid in that it contains very nearly the same percentage of phosphorus but its properties and reactions differ in several important particulars from those of phytic acid.

The synthesis of phytic acid or inosite hexaphosphoric acid cannot be considered as accomplished and it appears doubtful if this substance can be successfully synthesized by the methods heretofore employed.

EXPERIMENTS ON CARBOHYDRATE METABOLISM AND DIABETES.

II. THE RENAL THRESHOLD FOR SUGAR AND SOME FACTORS MODIFYING IT.

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(Received for publication, June 14, 1920.)

Attention was called in the preceding communication¹ to the importance of renal permeability in determining the apparent tolerance for sugar. The present group of papers, together with that of Palmer² on tissue permeability, are fragments of a research originally planned on the passage of sugar through different body membranes in diabetic and non-diabetic conditions. Publication of the following incomplete observations is ventured because of the apparent suggestiveness of some of them.

No detailed survey of the literature on the permeability of the kidney for sugar will be attempted. Some of the older literature was reviewed by Allen,³ and the principal facts bearing on the present topic may be summarized as follows: (a) a brief glycosuria is attended by a lowering of the sugar threshold of the normal kidney, so that as the hyperglycemia is subsiding sugar continues to pass into the urine with a lower level of blood sugar than that which is necessary to cause glycosuria at the outset; (b) prolonged glycosuria or hyperglycemia is attended with an elevation of the sugar threshold, so that glycosuria may remain absent with a blood sugar level considerably higher than that at which sugar excretion ordinarily occurs; (c) renal abnormalities, either spontaneous diseases or drugs and other agencies, may either increase

¹ Allen, F. M., and Wishart, M. B., *J. Biol. Chem.*, 1920, xlii, 415.

² Palmer, W. W., *J. Biol. Chem.*, 1917, xxx, 79.

³ Allen, F. M., *Studies concerning glycosuria and diabetes*, Cambridge, 1913, 44, 384 ff., 541.

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or diminish the permeability. Epstein and Baehr⁴ and Woodyatt⁵ have emphasized the importance of blood volume in addition to the percentage concentration of sugar for governing the excretion. This, however, is presumably only one of many factors influencing renal permeability. The present observations were accompanied with hemoglobin and corpuscle percentage determinations, as illustrated in the following and other papers, and were not explainable by blood volume changes as far as could be judged by these methods.

Benedict and Osterberg⁶ have recently placed this subject on a new basis, by devising a quantitative method for the sugar in normal urine. With this procedure there is no renal threshold for glucose, and various metabolic conditions can be more accurately studied in their influence upon the kind as well as the quantity of urinary carbohydrate. Two excuses may be offered for presenting observations based upon the older idea of the renal threshold and a fixed distinction between glycosuria and its absence as opposed to the newer concept of normal and pathological variations of glycaemia. One is that so many matters of experimental and clinical importance have been connected with the excretion of sugar according to the older standard, that though this may now be subject to modification it can scarcely lose its significance altogether. The other is the likelihood that all valid standards will be found to agree, and that the finer observations with the new method may in general confirm the cruder ones with the old. The present findings may therefore at least suggest causes of altered renal permeability which are worth investigating by the improved method.

A large number of parallel analyses of urine by copper reduction according to Benedict and of blood by the Benedict picric acid method have been performed in the course of the entire investigation, but relatively few are suitable for fixing the threshold or permeability. Consideration is therefore limited chiefly to forty-nine dogs, from which parallel samples of blood and urine were obtained at 15 minute or other suitable intervals, or the

⁴ Epstein, A. A., and Baehr, G., *J. Biol. Chem.*, 1914, xviii, 21. Epstein, A. A., *Proc. Soc. Exp. Biol. and Med.*, 1915-16, xiii, 67; *Am. J. Med. Sc.*, 1917, cliv, 103.

⁵ Woodyatt, R. T., *The Harvey Lectures*, 1915-16, xi, 326.

⁶ Benedict, S. R., and Osterberg, E., *J. Biol. Chem.*, 1918, xxxiv, 195.

urine alone was collected frequently and a blood sample taken as soon as a reducing reaction appeared or disappeared. The experiments were seldom performed directly for this purpose, but by bearing this point in mind it was easily included as an incidental observation in experiments of various kinds. The number of observations is multiplied by the fact that they were repeated in all the above dogs under different experimental conditions. The animals most often mentioned are those in which the changes were followed through successive stages of diabetes. The results are briefly summarized under the respective types of experiments (fasting, different injections, feedings, etc.), and the individual dogs under each heading are arranged in order according to the gradations of tolerance or diabetes.

The degree of diabetes is naturally something which cannot be defined exactly, but for this purpose dogs were considered severely diabetic if they showed glycosuria on protein diet, and mildly diabetic if considerable quantities of carbohydrate were necessary for glycosuria. Such diabetes was merely "potential" except on test days, because active symptoms were kept absent as a rule by appropriate diets. Other dogs had undergone removal of $\frac{3}{4}$ or more of the pancreas, but not enough to produce diabetes. These and the normal dogs were on bread and soup diets. The others were on such protein diets as were necessary for sugar freedom, with addition of fat sometimes as specified.

Fasting Plasma Sugars.

The dogs were fed between 10 a.m. and noon, and the blood samples designated as "fasting" were taken before feeding the next day. Table I gives a summary of the results.

As the conditions specified preclude any glycosuria, this group naturally includes no observations of threshold. The plasma sugar values found for the normal animals agree with those in the literature and with numerous others in the course of this research. Those of the partially depancreatized non-diabetic animals are entirely similar, there being no tendency to fasting hyperglycemia from the removal of pancreas tissue to any point short of diabetes. They may, however, be more readily subject to hyperglycemia from slight excitement or other disturbance,

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thus accounting for the maximum of 0.154 per cent. The values are observed to rise with increasing severity of diabetes. The important point in the present connection is that these levels were reached and maintained for long periods without glycosuria. As heavy glycosuria always accompanies such values normally, it must be concluded that there is a marked elevation of the sugar threshold with increasing severity of diabetes. This corresponds to the observations in the great majority of human cases.

The rôle of the long continued excess of sugar itself will be discussed below. Some part may be attributed to it in most of the above animals, as also in most human cases, because of the history of long continued glycosuria or hyperglycemia in most of

TABLE I.

Condition.	No. of dogs	No. of analyses.	Plasma sugar.		
			Maximum.	Minimum.	Average.
			<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
Normal.....	10	14	0.121	0.070	0.108
Partially depancreatized non-diabetic...	10	46	0.154	0.065	0.109
Mild diabetes.....	11	43	0.200	0.084	0.143
Severe diabetes.....	18	51	0.357	0.109	0.196

them. That a very prolonged excess of sugar, however, is not essential to such elevation of the threshold is proved by the records of certain animals.

Dog D4-28 was previously described.⁷ $\frac{1}{2}$ of the pancreas was removed⁸ on Sept. 28, 1916, and the dog was radically undernourished, so that hyperglycemia was brief and rare. Nevertheless in a feeding test on Dec. 1, 1917, the plasma sugar went to 0.216 per cent without glycosuria. It may be worth noticing that the diet had contained considerable fat.

Dog F6-08, a male Dalmatian aged 3 years, weighing 15 kilos, on Dec. 6, 1917, underwent removal of 27.9 gm. of pancreatic tissue, leaving a remnant estimated at 1.4 gm. ($\frac{1}{4}$). With fasting there was no glycosuria, but the plasma sugar on the morning of Dec. 8 was 0.179 per cent. Additional bits of pancreatic tissue were removed for microscopic examination on Dec. 14 and 19. 100 gm. of bacon grease were fed daily after Dec. 24, no other food being given. Dec. 31, at a weight of 8.5 kilos, the plasma sugar was 0.256 per cent without glycosuria.

⁷ Allen, F. M., *J. Exp. Med.*, 1920. xxxi, 581-583.

⁸ All operations were performed under ether anesthesia.

Dog F6-09, a shaggy male mongrel aged 8 years, weighing 18.75 kilos, on Dec. 6, 1917, underwent removal of 36.2 gm. of pancreatic tissue, leaving a remnant estimated at 2.6 gm. ($\frac{1}{16}$). With fasting there was no glycosuria, and the plasma sugar was 0.242 per cent on Dec. 8 and 0.192 per cent on Dec. 10. Without food and without glycosuria, the plasma sugar had risen by Dec. 13 to 0.313 per cent.

Dog F6-11, a female mongrel aged 6 years, weighing 19 kilos, on Dec. 19, 1917, underwent removal of pancreatic tissue weighing 26.3 gm., leaving a remnant estimated at 1.9 gm. ($\frac{1}{4}$ to $\frac{1}{16}$). With fasting and continuous absence of glycosuria, the plasma sugar on Dec. 26 was 0.278 per cent and on Dec. 27, 0.357 per cent.

Subcutaneous Glucose Injections.

Glucose was injected subcutaneously in fasting dogs in 30 per cent solution. Satisfactory threshold figures were obtained in only three partially depancreatized non-diabetic animals and one with mild diabetes.

Dog B2-00, weighing 14 kilos (at a stage when removal of about 1 gm. of additional pancreatic tissue was found necessary to produce diabetes), had a fasting plasma sugar of 0.065 per cent, and received 3 gm. of glucose per kilo subcutaneously. Slight glycosuria occurred with 0.163 per cent of plasma sugar, and a trace could still be detected when the plasma sugar had fallen to 0.118 per cent.

Dog B2-01, with a similar weight and condition, had a fasting plasma sugar of 0.099 per cent, and received 4 gm. of glucose per kilo subcutaneously. With the first trace of glycosuria the plasma sugar was found to be 0.151 per cent. 5 months later the same dose was given. Starting with a fasting plasma sugar of 0.106 per cent, with the first trace of glycosuria the plasma sugar was found to be 0.147 per cent. The threshold had thus apparently not changed with time in a non-diabetic dog on bread diet.

Dog B2-61, weighing 5 kilos and possessing $\frac{1}{2}$ of the pancreas, received 3 gm. of glucose per kilo and showed almost a titratable glycosuria when the plasma sugar reached 0.147 per cent (from a fasting level of 0.106 per cent).

Dog B2-79, weighing 15 kilos, in the stage of mild diabetes, with a remnant of $\frac{1}{2}$ of the pancreas, was kept nearly constantly free from glycosuria on a diet of beef lung, and 5 months after operation received 5 gm. of glucose per kilo subcutaneously. Starting with fasting plasma sugar of 0.105 per cent, a strong trace of sugar appeared in the urine with a plasma sugar of 0.182 per cent. The threshold thus seemed slightly elevated as compared with the non-diabetic animals.

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Intravenous Glucose Injections.

With the method of discontinuous injections described in the preceding paper,¹ the threshold of disappearance of glycosuria after the injections are finished is all that can be determined accurately.

Three normal dogs were thus observed, which received 1.5 gm. of glucose per kilo per hour. In one of these glycosuria disappeared while the plasma sugar fell from 0.173 to 0.150 per cent, and in another while the plasma sugar fell from 0.154 to 0.143 per cent. In the third there was a very faint urinary reaction at 0.167 per cent of plasma sugar, and with completely negative urine the plasma sugar was down to 0.128 per cent.

Dog B2-00, partially depancreatized just short of diabetes, received similar dosage and became aglycosuric as the plasma sugar fell from 0.145 to 0.130 per cent.

Dog B2-01, with very mild diabetes, showed a very low threshold as noted in the preceding paper,⁹ the urine giving a slight copper reduction during this time while the successive plasma sugars were 0.084, 0.087, and 0.116 per cent.

Three other dogs with slightly greater diabetic tendency showed thresholds between 0.140 and 0.123 per cent, between 0.228 and 0.200 per cent, and between 0.212 and 0.200 per cent, respectively. Here the first dog with the lowest threshold had the smallest pancreas remnant but had also been kept free from glycosuria and hyperglycemia.

The concentration of the solutions used in the above mentioned tests ranged from 5 to 20 per cent, but showed no constant relation to the different thresholds of disappearance of glycosuria. On the other hand, comparisons may be made with identical doses at different stages of diabetic progress in a dog previously described.¹⁰ Here the thresholds are not exact, because the hour intervals are too long for accuracy, but the comparative relation holds. The table in the reference cited shows that on August 6, 1917 (3 days after the final pancreas operation which produced very mild diabetes), during 2 hours following the last injection there were traces of glycosuria with plasma sugars of 0.125, 0.128,

⁹ Allen and Wishart,¹ p. 439.

¹⁰ Allen, F. M., *J. Exp. Med.*, 1920, xxxi, 567.

and 0.130 per cent, successively. Glycosuria was then absent in the next hour during which the plasma sugar rose to 0.133 per cent (indicating disappearance of the special glycosuric tendency which persists for a time during the decline of a glycosuria). On November 19, 1917, there was only a faint trace of glycosuria in the 1st hour after injections with plasma sugar falling from 0.322 to 0.156 per cent, and none in the next hour with plasma sugar between 0.156 and 0.147 per cent. On February 19, 1918, glycosuria disappeared during the 2nd hour after injections with the plasma sugar somewhere between 0.294 and 0.170 per cent, for there was a bare trace of copper reaction in the urine of this hour and none immediately thereafter. Another comparison also can be made between these three dates, by consideration of the fact that the blood analyses during the injection periods were always performed 15 minutes after an injection, just before the next injection. They are thus minimum values, and though not establishing a threshold afford one basis of comparison. The table mentioned shows a change in sugar excretion on this basis. For example, at the 6th and 7th hours on August 6, with plasma sugars of 0.270 and 0.202 per cent, the glycosuria was 1.81 and 1.45 per cent. At the 6th and 7th hours on November 19, with plasma sugars of 0.356 and 0.370 per cent, the glycosuria was 0.28 and 0.55 per cent. At the 6th and 7th hours on February 19, with plasma sugars of 0.475 and 0.455 per cent, the glycosuria was 2.78 and 4.35 per cent. The differences exist likewise if the urine volume and quantitative sugar output are considered. In general, as the diabetes advanced and the dog was subjected to more prolonged hyperglycemia, the sugar threshold rose, but yet with the more severe diabetes there was a more active sugar excretion on February 19 than on November 19.

Dog B2-79, in the stage of severe diabetes over a year after operation, received 1 gm. of glucose per kilo per hour and did not show glycosuria when the plasma sugar had reached 0.230 per cent. In another experiment with 1.5 gm. per kilo per hour, the threshold of disappearance of glycosuria is shown in the table in the preceding paper.¹¹ There was very faint glycosuria from 3.45 to 4 p.m., while the plasma sugar was falling from 0.264 to 0.208 per cent, and none from 4 to 4.15 with plasma sugar of from 0.208 to 0.226 per cent.

¹¹ Allen and Wishart,¹ p. 450.

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Carbohydrate Feeding.

The normal dog, No. C3-32, weighing 36 kilos, was given 1 liter of 50 per cent glucose solution by stomach tube. The results are shown in Table I of the ensuing paper.¹² The first trace of glycosuria found in frequent catheterizations came after 30 minutes, and the blood sample taken at this time showed 0.222 per cent of plasma sugar. Thereafter the blood sugar concentration fluctuated (as sometimes happens with large doses and particularly with nausea, due probably to irregularities of absorption), but heavy glycosuria occurred with much lower hyperglycemia, although the blood became concentrated as judged by hemoglobin and corpuscle percentage estimations.

Dog B2-00, partially depancreatized non-diabetic, weighing 14 kilos, received 3 gm. of glucose per kilo in 30 per cent solution by stomach tube. The first trace of glycosuria was obtained with a plasma sugar concentration of 0.192 per cent.

Dog B2-60, partially depancreatized non-diabetic, weighing 45 kilos, received 12 gm. of glucose per kilo of body weight in 40 per cent solution by stomach tube, and the threshold was found to lie between 0.202 and 0.222 per cent.

Dog B2-00, above mentioned, was fed 100 gm. of beef lung, 200 gm. of bread, and 75 gm. of glucose. The threshold of disappearance of glycosuria was determined between 0.154 and 0.149 per cent. The next day the same food was given with increase of glucose to 150 gm. The glycosuria was heavier, and a bare trace was still present after 6 hours with the plasma sugar at 0.128 per cent. 2 days later the same diet was given, and after 6 hours a faint trace of glycosuria persisted with plasma sugar of 0.130 per cent.

Dog B2-60, after removal of more pancreatic tissue but still not quite diabetic, received a feeding test with 100 gm. of lung, 800 gm. of bread, and 200 gm. of glucose, repeated on 4 different days. The threshold of appearance of glycosuria was determined in close agreement in all four tests as lying between 0.200 and 0.222 per cent. This is practically identical with the former test with pure glucose.

Dog B2-00 was fed the above diet of 100 gm. of lung, 200 gm. of bread, and 150 gm. of glucose when in the stage of mild diabetes. The threshold of appearance of glycosuria was determined between 0.145 and 0.152 per cent. 6 weeks later the same diet was fed, after hyperglycemia during most of the interval and some aggravation of the diabetes, and the first trace of glycosuria was found with plasma sugar of 0.204 per cent.

Dog B2-01, in the stage of mild diabetes, received a feeding test of 100 gm. of lung, 200 gm. of bread, and 30 gm. of glucose, repeated four times at 2 day intervals. The threshold of appearance of glycosuria was almost exactly 0.130 per cent on all four occasions, and was thus in keeping with the uniformly low thresholds in the early record of this dog. 3 months

¹² Allen, F. M., and Wishart, M. B., *J. Biol. Chem.*, 1920, xliii, in press.

later, the diabetes meanwhile having been well controlled by diet, the same test was repeated. The threshold of appearance of glycosuria was 0.135 per cent. The threshold of disappearance was not exactly determined, but a trace of glycosuria remained when the plasma sugar had fallen to 0.128 per cent. The same test was repeated 1 year later, when the diabetes was still under control and glycosuria or hyperglycemia had been permitted only in occasional short experiments during the interval. The threshold of appearance of glycosuria was between 0.141 and 0.147 per cent. The threshold was thus evidently rising. But the naturally low thresholds of this dog find their strongest contrast in the terminal stage with maximal severity of diabetes, when the plasma sugar was 0.322 per cent during fasting without glycosuria.¹³

Dog B2-02 was tested in the stage of mild diabetes after a meal of bread and soup, and glycosuria appeared with a plasma sugar concentration of 0.162 per cent.

Dog B2-88 was tested at a stage when the diabetes was mild but yet more advanced than that of the preceding dogs, so that chronic hyperglycemia was present on mixed diet. The fasting plasma sugar was 0.189 per cent. After a feeding test of 100 gm. of lung and 200 gm. of bread, it rose in successive analyses to 0.257 per cent without glycosuria, and 5 hours after feeding the first faint trace of glycosuria appeared with 0.286 per cent plasma sugar.

Protein Feeding.

As glycosuria from protein was taken as the criterion of severe diabetes, it follows that a renal sugar threshold on protein feeding can be determined only in severe cases. There is a considerable intermediate class of dogs (like a corresponding class of human patients) which have chronic hyperglycemia on protein diets, with no glycosuria even though the plasma sugar is constantly above the threshold of normal individuals. After a protein meal there is often a rise of blood sugar like that following carbohydrate in milder cases. As examples may be mentioned plasma sugar concentrations of 0.204, 0.222, 0.232, and 0.294 per cent in four dogs of this series under these conditions without glycosuria. These values do not establish thresholds, except that it can be said that the thresholds lie above these levels.

Examples of sugar thresholds on protein diets are given incidentally elsewhere, particularly under "Fat feeding." The question whether the protein itself has any influence upon the threshold in severe diabetes cannot receive a clear answer under the condi-

¹³ Allen, F. M., *J. Exp. Med.*, 1920, xxxi, 600.

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tions, for since these dogs cannot tolerate adequate protein diets it follows that in any prolonged experiments they must have been subjected to fat feeding, hyperglycemia, or marked under-nutrition, any of which may possibly affect the threshold. In short experiments there is evidence that the threshold is approximately the same whether the hyperglycemia is produced by protein or by carbohydrate.

Special Influences Affecting the Threshold.

A. Fasting.—

Dog B2-00, partially depancreatized non-diabetic, as above mentioned under "Subcutaneous glucose injections," received 3 gm. of glucose per kilo and showed slight glycosuria with 0.163 per cent plasma sugar. After the dog had fasted for 1 week the same subcutaneous dose was repeated, and the plasma sugar reached 0.238 per cent without glycosuria.

Dog C3-22, with severe diabetes which had been partially controlled for 6 weeks with diets very high in fat, showed hyperglycemia as high as 0.256 per cent without glycosuria. After 5 days of fasting, a feeding test fixed the threshold of appearance of glycosuria at 0.159 per cent.

The different effects of fasting possibly have some relation to the preceding diet.

B. Excess of Sugar.—Under "Fasting plasma sugars" mention was made of the fact that the high thresholds characteristic of severe diabetes are generally found after long standing hyperglycemia, and the latter is with some reason regarded as a factor in raising the threshold, though some examples were given of high thresholds after briefer hyperglycemia. A normal cat subjected to subcutaneous glucose injections through many months¹⁴ developed a remarkable pathologic condition, particularly with regard to nervous manifestations, and at the close a blood sugar concentration of 0.539 per cent was found without glycosuria. The simple osmotic disturbance of the subcutaneous injections may have been responsible for the high sugar threshold as well as for the other pathological symptoms. Dogs B2-00 and B2-01, frequently mentioned in this and preceding papers,¹⁵ were among numerous animals subjected to the highest possible carbohydrate diets through months and years, without elevation of the thresh-

¹⁴ Allen,³ pp. 159, 164, 168. Microphotograph of adrenal medulla, Fig. 1.

¹⁵ Allen, F. M., *J. Exp. Med.*, 1920, xxxi, 396; Allen,³ pp. 562, 564.

old before they became diabetic. Allowance must be made for the fact that the hyperglycemia in such animals is generally brief, and is never actually continuous over any long time unless the animal becomes diabetic. A considerable degree and duration of hyperglycemia are occasionally attained in certain dogs barely on the edge of diabetes, as Dog B2-86, previously described.¹⁶ After removal of about $\frac{4}{5}$ of the pancreas on April 7, glycosuria was maintained almost daily by enormous glucose diets. In the feeding test with 400 gm. of bread and 200 gm. of glucose on May 4, the urine taken at frequent intervals first showed sugar about the end of the first $\frac{1}{2}$ hour, with plasma sugar of 0.196 per cent. From the table given for May 13 it may be judged that the threshold on that date was not far different. The threshold therefore seems to be slightly elevated as compared with the normal; but as the dog was old and his threshold before the pancreas operation had not been determined a conclusion is unsafe. Furthermore, the tables referred to furnish evidence that important hyperglycemia must have been present for about a month, yet the threshold was not so high as that of severely diabetic dogs a few days after operation.

C. Fat Feeding.—Most of the severely diabetic patients and animals with high sugar thresholds have been on diets containing considerable fat for longer or shorter periods. This factor cannot be excluded in any of the high thresholds of severely diabetic animals mentioned thus far, except in a few cases of fasting. The thresholds have been noticeably high in the animals receiving the highest fat diets, and one of the highest in the series was observed under these conditions.¹⁷ Here the threshold was evidently above 0.4 per cent, and the suggestion was made that excessive fat feeding may affect the kidney function injuriously.

Some indications of a direct influence of fat seemed to be furnished by Dog B2-79. The high thresholds previously mentioned (p. 135) were obtained after very high fat diets (up to 300 gm. of lard or suet daily for over a month). Then for 5 days the only diet was 500 gm. of lung daily without glycosuria. At the end of this time a meal of 1 kilo of lung was given, and glycosuria began when the plasma sugar reached 0.159 per cent. The high

¹⁶ Allen, ¹⁶ p. 385.

¹⁷ Allen, F. M., *Am. J. Med. Sc.*, 1917, cliii, 348, 352.

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fat diets were then resumed for 3 days, after which a fasting plasma sugar of 0.200 per cent was found without glycosuria. After 2 months more of diets consisting predominantly of fat, a protein-feeding test showed a threshold of 0.334 per cent.

Several observations indicate that a single feeding with fat has no demonstrable influence on the sugar threshold. No prolonged experiments with fat feeding were performed in normal or mildly diabetic animals.

D. Acidosis.—This was one of the factors considered by Fitz¹⁸ in his study of the renal function in diabetes. It can be excluded in regard to most of the high thresholds and also the fat diets of this series, because the dogs were free from acidosis. Dog B2-79 had slight acidosis with some of the thresholds mentioned, and Dog C3-56 had more marked acidosis at certain times. Sugar thresholds were not obtainable in coma cases in dogs because of the continuous glycosuria.

Considerable hyperglycemia without glycosuria may be found in experiments with large intravenous injections of either acetone bodies or mineral acids, such as will be described elsewhere, but the renal changes can scarcely be classified as typical of acidosis because of the chance that they are due merely to this mode of administration of a toxic foreign substance.

E. Cold.—The opportunity was taken to determine approximately the sugar thresholds of several dogs used for experiments with cold to be described elsewhere,¹⁹ but this degree of cold seemed to produce no important alterations as compared with the thresholds of the same dogs at ordinary temperatures.

F. Exercise.—No sugar thresholds were determined in exercise experiments, but the normal dog, No. B2-90, with exercise alone attained a plasma sugar concentration of 0.256 per cent without glycosuria, which is probably higher than the threshold of any normal dog under ordinary conditions.

G. Infections.—A normal dog shortly before death from rabies had a plasma sugar of 0.450 per cent without glycosuria. Sugar thresholds were not determined in dogs with ordinary infections and would probably have little significance because of the varying grades of renal injury to be expected in such cases.

¹⁸ Fitz, R., *Arch. Int. Med.*, 1917, xx, 809.

¹⁹ Allen, F. M., *Experimental Studies on Diabetes*, Series II, Paper 7.

H. Hemorrhage.—A normal dog, weighing 10.8 kilos was bled rapidly from the femoral artery to the amount of 500 cc. The preparation had been made in advance so that there was no pain or struggle. The plasma sugar at the beginning of bleeding was 0.121, at the end 0.238 per cent, without glycosuria. The hyperglycemia of hemorrhage is well known, and the apparently elevated threshold agrees with observations of Wilenko²⁰ and of Epstein and Baehr.⁴

I. Unilateral Nephrectomy.—

Dog D4-69 in January, 1917, underwent removal of the left kidney, followed by partial pancreatectomy not quite sufficient to produce diabetes. In March, on diets of bread and soup with 200 gm. of glucose, plasma sugar concentrations as high as 0.264 per cent were observed without glycosuria. No reason was known for the apparently elevated threshold except the kidney removal.

J. Epinephrine.—Pollak²¹ discovered that repeated injections of epinephrine diminish the renal permeability for sugar.

The normal dog, No. C3-92, weighing 17.6 kilos, on May 16, 1916, received 10 cc. of Parke-Davis adrenalin (1,000) solution subcutaneously. The threshold of appearance of glycosuria was determined at 0.152 per cent plasma sugar, the threshold of disappearance at 0.118 per cent. On May 23 the same dose was repeated, and the threshold of appearance of glycosuria was approximately 0.380 per cent. The dose was repeated May 29, and the plasma sugar rose to 0.418 per cent without glycosuria. Lard was fed on May 23 and white clay as a control on May 29. Probably neither of these influenced the threshold, for several similar examples could be cited which are free from such factors; but it seems true nevertheless that the diuretic activity and other accessory conditions influence the sugar threshold with epinephrine. Especially in fasting animals plasma sugars as high as 0.278 per cent have been seen with the first dose of epinephrine without glycosuria.

K. Drugs.—Narcotics and other drugs which produce hyperglycemia and glycosuria (supposedly due largely to asphyxia) at the same time impair the renal function for sugar. For example, a normal dog was deeply narcotized with magnesium chloride intramuscularly, and when near death was partially revived with calcium chloride intravenously. A trace of sugar

²⁰ Wilenko, G. G., *Arch. exp. Path. u. Pharmacol.*, 1912, lxviii, 297.

²¹ Pollak, L., *Arch. exp. Path. u. Pharmacol.*, 1909, lxi, 376.

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appeared in the urine when the plasma sugar reached 0.500 per cent. Figures almost as high have been found with the huge doses of morphine necessary for deep narcosis of dogs. Examples of such drug action might be multiplied, probably without much significance.

L. Pancreatic Function, or Severity of Diabetes.—One of the questions of chief interest was a possible relation between the renal function and the internal pancreatic function. It may be noticed under "Fasting plasma sugars" that the dogs which developed a high renal threshold very early after operation were those which had very small pancreas remnants and correspondingly severe diabetic tendencies. On the other hand, clinical literature contains occasional statements that some cases of diabetes begin with glycosuria with little or no hyperglycemia. To obtain information whether complete lack of the pancreatic function may make the kidneys more or less permeable for sugar, observations of the threshold of appearance of glycosuria were carried out on two totally depancreatized dogs.

Dog C3-01, a collie aged 3 years, thin at a weight of 15 kilos, after 24 hours of fasting before operation had plasma sugar of 0.099 per cent. In the midst of the operation, when the entire pancreas had been dissected free except that its duct and principal blood vessels were not yet severed, the plasma sugar was 0.236 per cent without glycosuria. On removal from the table 15 minutes later glycosuria was still absent and remained so for 2½ hours; then with the appearance of slight glycosuria the plasma sugar was 0.270 per cent. At the end of 5 hours the plasma sugar was still 0.270 per cent, with 1.6 per cent urinary sugar. On the following days, with the usual heavy glycosuria during fasting, the plasma sugars ranged between 0.3 and 0.5 per cent.

Dog C3-60, a mongrel, in medium condition at a weight of 12.5 kilos, had plasma sugar of 0.208 per cent immediately after total pancreatectomy, without glycosuria. The exact threshold was not determined, but 4 hours later there was heavy glycosuria with plasma sugar of 0.300 per cent.

Doubtless the state of nutrition, the anesthesia, and other accidental factors influence the exact threshold and the interval after operation at which glycosuria begins, but these and similar observations seem to exclude any abnormally low renal thresholds at any stage following total pancreatectomy.

DISCUSSION.

At least three groups of causes may be imagined for the alterations of renal function in diabetes; namely, (a) direct renal and vascular injuries, (b) general metabolic conditions, and (c) influences associated specifically with the diabetes.

(a) Clinical diabetes is not infrequently associated with some degree of nephritis or arteriosclerosis, and even where these are not evident there is a possibility that the same infection or intoxication which damaged the pancreas may have left some anatomic or functional injury in the kidney. Animal experiments offer the opportunity either of studying diabetes without these possible complications, or of producing different forms of renal injury for investigation. Though the supposition of an adrenal element in diabetes is opposed by weighty facts and supported by none, the use of epinephrine as a drug gives an interesting illustration of a toxic renal or vascular alteration. When the acute effects have subsided, it is questionable whether the finest study can reveal any anatomic changes, and the animals are certainly free from albuminuria and the ordinary clinical symptoms of nephritis. Yet there is an elevation of the sugar threshold which is far greater than can be accounted for by the brief hyperglycemia, and which is either permanent or at least of considerable duration. Animals which have undergone removal of $\frac{1}{2}$ to $\frac{3}{4}$ of their total renal tissue offer some points of interest not only for the sugar threshold in the old sense but also for their sugar excretion by Benedict's new method, for determining to what extent the latter represents general carbohydrate metabolism or merely a function of the kidney itself.

(b) Some general metabolic alterations might consist in accidentally associated endocrine disorders, which, notably in the case of the hypophysis, are recognized as affecting renal function. The nutritive state is another possible factor. The so called famine or war edema is presumably similar to that of many diabetic cases. The latter is usually accompanied by a high renal threshold for both sugar and salt, but the relation is not known to be invariable; equally high thresholds are found in cases without edema, and the etiology may be independent.

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Alterations in blood volume are a factor adequately discussed by authors already quoted. A possibility not much considered heretofore is an influence of food upon renal function. Barrenscheen²² claimed that an "oatmeal cure" may diminish the permeability of the kidneys for lactose, though the fact itself and the interpretation, whether due to carbohydrate, salt, or something else, may bear further investigation. On the other hand, there is abundant evidence that in the declining stage of a glycosuria there is ordinarily a lowering of the renal threshold, in the sense that sugar continues to pass into the urine at a level of plasma sugar concentration distinctly lower than that necessary to produce glycosuria in the first place. One hypothetical explanation may be suggested by the well known Armanni or Ehrlich phenomenon of glycogen deposition in certain segments of the renal tubules. If these deposits be accepted as representing sugar absorption by the tubule cells, it is conceivable that cells thus saturated may either continue for a time to discharge sugar, or (more probably) that they may fail to resorb sugar as actively as usual from the glomerular filtrate, and thus the prolongation of glycosuria might be explained under either of the theories of renal secretion. A possible influence of fat feeding is also suggested by other evidence. Chemical analyses in the literature indicate that the kidney is one of the organs in which fat is deposited during lipemia. Especially with heavy lipemia this can be confirmed microscopically, and it is interesting that the cells which stuff themselves with fat are the same ones which are filled with glycogen in glycosuria. The two may be combined; carmine stains then show the glycogen granules to be distributed around, not in, the vacuoles, and the latter are shown by Sudan stains to be fat. This fat infiltration accords with the traces of fat found in the urine with heavy lipemia, and can be interpreted according to either theory of renal secretion. If fat feeding causes a diminution of renal permeability for sugar, it may be associated in some unknown way with these morphologic changes or due to invisible alterations in cell membranes.

(c) One condition in diabetes which may affect the kidneys is the acidosis. This supposition is supported by the well known albuminuria and showers of casts appearing as precursors of coma.

²² Barrenscheen, H. K., *Biochem. Z.*, 1912, xxxix, 232.

This can, however, be easily excluded as a sole cause by the fact that dogs and most human patients studied in sufficiently early stages show a considerable elevation of the sugar threshold without acidosis. The typical onset of diabetes in all but the most acute cases seems to be by a gradual rise of blood sugar, frequently traceable through months in both animals and patients, before glycosuria appears; there is generally continuous hyperglycemia in the next stage of occasional or "alimentary" glycosuria, and generally next a period of continuous glycosuria without acidosis. In most cases at any of these stages the sugar threshold is found to be already high.

This elevation of the threshold may be attributed to the prolonged hyperglycemia itself, a common notion being that the kidney by habituation comes to "tolerate" glucose. This explanation may contain much truth, but yet it appears that a high threshold may develop very early in severe diabetes and may be absent after more intense and prolonged hyperglycemia and glycosuria in normal or mildly diabetic animals. Also, if this elevation is a mere habituation, it might be expected to be lost after removal of the cause, but in the writers' experience severely diabetic patients and animals have shown characteristically high sugar thresholds after a year or more of continuously normal blood sugar. The reason for the low thresholds of exceptional clinical cases is also not clear.

A specific relation of the renal and pancreatic functions is not demonstrable in the sense of any increased readiness of sugar excretion following total pancreatectomy. An opposite view is sometimes entertained, that the elevated sugar threshold is to be regarded as a protective mechanism for saving sugar to the body. It might further be considered plausible that this device is more needed and called more into play with increasing severity of the diabetes. There is no real disproof of this assumption. It is true furthermore that some extra utilization of carbohydrate is probably forced by any obstruction of excretion, according to the principle of the metabolism of plethora, as long as any appreciable power of utilization is retained by the organism. It was thus found in the preceding paper that renal impermeability confuses judgment of the urinary findings in glucose tolerance tests, particularly intravenous tests of short duration. It has less influence

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upon feeding tests or any tests of long duration, because the blood sugar rises high enough to cause heavy glycosuria even at the higher threshold. Theoretically the interpretation of the elevated threshold as a teleologic adaptation is an unproved and improbable assumption. The chief error which can be refuted is the supposition that the renal impermeability is of any real benefit to the diabetic organism in a practical sense. This involves the usual confusion between diabetes and glycosuria, and is closely allied to the discredited clinical practice of giving arsenic, uranium, and other drugs which perhaps to some extent suppress glycosuria by injuring the kidneys. Two important principles, which are perfectly clear in animal experiments, are equally applicable clinically. First, diabetes is deficiency of the internal secretion of the pancreas, and this deficiency cannot be compensated by any mere blocking of renal excretion. An extreme illustration is in totally depancreatized dogs, which die all the more quickly when their sugar is dammed back by nephrectomy or ureteral ligation. Second, the essential trouble to be combated in diabetes is not the mere loss of food material in the urine. The saving by renal impermeability, and also the metabolism of plethora induced by increased sugar concentration in the blood, can readily be equalled in the milder forms of diabetes by increasing the diet, and as the latter process is harmful the former may be expected to prove so likewise. In severe diabetes the damming back of metabolic products which cannot be utilized is a still more serious complication, as above mentioned. Some clinical illustrations of the above statements are found in the symptoms which occurred with trivial glycosuria and plasma sugar of 0.73 per cent in a patient with combined diabetes and nephritis,²³ and the occurrence of typical diabetic symptoms and complications in patients with hyperglycemia with little or no glycosuria because of a high renal threshold.²⁴

The chief criticism of the results contained in this communication is that they possess only the suggestiveness which is more proper to clinical observations, and could not be followed up with

²³ Allen, F. M., Stillman, E., and Fitz, R., Total dietary regulation in the treatment of diabetes, Monograph of The Rockefeller Institute for Medical Research, No. 11, New York, 1919, Case 61, 413.

²⁴ Mitchell, J. W., *Am. J. Med. Sc.*, in press.

conclusive methods and controls to establish causes and laws in the manner to be expected from animal experiments. The following deductions are possible concerning some of the points chiefly in view.

CONCLUSIONS.

1. A diminished renal permeability for glucose, in the sense of a raised threshold according to tests with Benedict's copper solution, is definitely proved as the rule in diabetic animals. As the same rule holds for the great majority of human diabetics, this demonstration furnishes one more point of similarity between the experimental and clinical conditions.

2. Various possible causes for the elevation of the threshold are discussed. The prolonged excess of sugar in the blood may be an important factor, but some considerations seem to oppose it. Certain observations suggest that high fat diets may raise the sugar threshold in diabetes even without acidosis. The renal function may be affected by various extraneous causes, of which the elevation of the threshold by epinephrine is one interesting example.

3. No interrelation of the renal and pancreatic functions is demonstrable in the sense of an increased readiness of sugar excretion even in totally depancreatized animals. An elevation of the threshold seems to be connected particularly with severity of the diabetes, but a teleological interpretation of this as a protective mechanism for saving sugar to the body is considered improbable.

DETERMINATION OF IODINE IN CONNECTION WITH STUDIES IN THYROID ACTIVITY.

THIRD PAPER.

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In 1912 I published a method for the determination of iodine in the presence of the other halogens and organic matter (1). In 1914 the method was modified in part (2), and during the past 6 years has been in constant use. Recently it has become necessary to determine the iodine content of animal tissues, and, as no method yet published was suitable for this work, attempts were made to refine the method published in 1914, in order to make it applicable for the determination of the iodine in blood and tissue.

The faults of the iodine method, previously described, apply entirely to the solution obtained after fusion with sodium hydroxide. The fusion originally described is still used without change.

In trying to improve the accuracy of the method, it was first necessary to secure a perfect blank in the absence of iodide. It was pointed out in a previous paper (2) that the presence of salts assists rather than interferes with the liberation of iodine from potassium iodide by an oxidizing agent. Blanks were therefore prepared, using sodium phosphate made by neutralizing the amount of sodium hydroxide required by the method with phosphoric acid. The neutralization was carried to the turning point of methyl orange. When such a solution was oxidized with bromine, then cooled, and phosphoric acid, potassium iodide, and starch were added, a perfect blank sometimes was obtained, but the blue color rapidly developed if the solution was allowed to stand.

In the determination it is essential to control the hydrogen ion concentration during the boiling with bromine. This is done by neutralizing the alkaline solution with phosphoric acid until methyl orange is just pink. This acidity, however, is not great enough for the final reaction between potassium iodide and the iodic acid resulting from the oxidation with bromine. It is necessary to add about 5 cc. of 20 per cent phosphoric acid at the time the potassium iodide is added. As we failed consistently to secure a perfect blank after oxidation with bromine, it appeared probable that the phosphoric acid which was used to acidify the solution at the time the potassium iodide was added was the cause for the liberation of iodine, and attempts were therefore made to obtain a perfect blank with nothing present except water and phosphoric acid. The test as finally adopted is as follows: 1 gm. of potassium iodide is placed in a dry flask. 15 cc. of phosphoric acid, 85 per cent, syrupy, are added to the potassium iodide. This produces a yellow color which, however, is not free iodine. The flask is allowed to stand for 15 minutes. 100 cc. of water are added. This will cause a partial or complete disappearance of the yellow color. After starch is added the solution should remain colorless. With the phosphoric acid available on the market it is rarely possible to obtain a perfect blank after such a procedure.

Since within the phosphoric acid itself there is a source of error causing high results, it is necessary to treat the acid so that this oxidizing action may be removed. This may be accomplished by diluting the phosphoric acid with four equal volumes of water, placing in a large beaker, and boiling the solution after the addition of a suitable amount of aluminum in the form of strips. It was found that the reduction proceeds slowly and requires prolonged boiling. It is possible to reduce all oxidizing agents so that when 25 cc. of the reduced acid are added to 1 gm. of potassium iodide, the solution is allowed to stand 15 minutes, and water and starch are added, a perfect blank will be obtained which will remain colorless for at least 15 minutes. When phosphoric acid which has been so reduced is used, the method is found to give very much more consistent results, and the solutions will remain colorless after titration for as long as from 30 to 45 minutes. It is unnecessary to reduce the phosphoric acid used to

neutralize the sodium hydroxide. Treatment of the solution with bromine destroys the oxidizing action of the impurities in the phosphoric acid.

In the original method talcum was recommended for the rapid removal of bromine from the solution. It was found, however, that when the talcum settled to the bottom of the titration flask the solution turned blue, suggesting that the talcum, although it caused a rapid expulsion of bromine from the solution, had retained a small amount which was absorbed in some manner and was not reduced by boiling with salicylic acid. Another disadvantage was the cloudiness of the solution. A solution turbid with talcum is very much more difficult to titrate than a water-clear solution. Some substitute for talcum was urgently needed. Many different substances were tried among which may be mentioned sand, brick, granite, pumice stone, capillary glass tubing, paper fibers, asbestos fibers, powdered charcoal, powdered glass, powdered porcelain, powdered hard coal, coke, and eventually hard coal in lumps of about 0.5 cm. in diameter. It was found that some of these agents assisted slightly in producing rapid boiling, but they all, except the paper fibers, retained traces of bromine which liberated iodine, giving high results. The paper fibers caused a slight reduction of the iodic acid.

Hard coal in lumps possesses a unique power to induce rapid boiling, but it also absorbs small amounts of bromine, so that after the titration is finished the solution in the immediate vicinity of the lump of coal turns blue, even in a flask which should be a perfect blank. In order to prevent high results from the oxidation by the bromine held in the coal, it was decided to remove the piece of coal after the solution had been boiled, and before titration. In order to accomplish this, two pieces of coal were tied together with a piece of thread. This thread could be picked up easily with a glass rod terminating in a hook. When pieces of coal tied together with a thread are used a number of times, added iodine cannot be quantitatively recovered, and it was found that the explanation for the low results is the reduction of iodic acid by the thread. It was a simple matter to change the thread to a glass hook which was passed through a hole in the lump of coal made by a dental drill. For some time coal which was removed by means of a glass hook was used, the coal

being washed between determinations and used a large number of times. This, however, was found impracticable, since there is a slow oxidation of the coal by the bromine, resulting in a softening and disintegration which eventually has the effect of reducing iodic acid and causing low results.

Since coal can be prepared in any desired amount with trivial trouble and expense, it was decided to use a fresh piece of coal for each determination. The method now employed is to use a piece of coal about 0.5 cm. in diameter and, after the solution has been boiled and cooled, it is removed by means of a small shovel made from a piece of sheet silver attached to a glass rod. This procedure is very easily carried out, the coal does not reduce iodic acid when used but once, and if it is removed from the solution a perfect blank can be obtained in the absence of iodine.

The method now possessed a high degree of accuracy except for the possible presence of substances other than iodic acid which were in the water or resulted from the solution of the fusion. In attempting to remove such oxidizing agents the solution was boiled with a considerable excess of sodium bisulfite and it was found that when iodine is present in amounts of from 5 to 10 mg., which is the upper limit of amounts that are desired to be determined by this method, the boiling in acid solution with sodium bisulfite does not result in the loss of any iodine. Boiling with sulfite reduces all nitrites and other oxidizing agents and prepares the solution for oxidation. Oxidation of such a solution with bromine causes a quantitative production of iodic acid.

Another point which is essential to control is the hydrogen ion concentration of the solution. This we find to be of greatest importance. In the presence of too high a concentration of hydrogen ion, hydrobromic acid will react with iodic acid, causing low results. Even 5 cc. of 50 per cent phosphoric acid in excess may cause an appreciable loss of oxidizing power due to reduction of iodic acid. It was eventually found that titration to the first pink color with methyl orange, after which 5 cc. of 20 per cent phosphoric acid are added, produces a proper acidity for both the reduction with sodium bisulfite and the subsequent boiling with bromine.

In the original method it was recommended to use a 10 per cent solution of potassium iodide. All commercial potassium

iodide will liberate traces of iodine on long standing in aqueous solution. This iodine could be removed with thiosulfate, but the addition of potassium iodide in solid crystalline form to the solution has been found to be the most convenient method for the addition of this salt.

The last point which requires control is the length of time of boiling the solution. It has been found that the solution may be boiled in the presence of sodium bisulfite until a large part of the water has been evaporated without loss of iodine. The solution must be boiled 10 minutes as a minimum length of time, in order to remove all traces of sulfurous acid. The oxidation with bromine is best carried out in a solution of a volume of 200 cc. It is best therefore to have sufficient water present before boiling off the sulfurous acid so that at least 10 minutes are necessary to bring the volume to 200 cc. This volume is marked on each flask. If more time is required to reduce the volume of the solution to the mark it is without effect on the subsequent determination of the iodine. The only essential point is that each flask boils at least 10 minutes.

Although there is a wide limit to the time for boiling with sulfite, it is essential to regulate closely the time of boiling with bromine. If the boiling with bromine is prolonged after the excess has been removed from the solution, low results are produced. A series of experiments has shown that the best time for boiling with bromine is 5 minutes after the solution is colorless. It requires approximately 3 minutes for the bromine to be expelled from the solution after boiling begins, and if the boiling is continued for 5 minutes more a perfect blank will result. As a further precaution, however, salicylic acid is added just before the flask is cooled. Although this may be unessential in most cases, its adoption is a safeguard which assures a uniform removal of the last traces of bromine from all determinations.

With the adoption of these six modifications of the original method, the determination of iodine after fusion in sodium hydroxide can be made with a high degree of accuracy. The method is of the greatest value, however, in the determination of minute amounts of iodine. The water-clear solution resulting by elimination of talcum permits a titration of amounts measured in hundredths of a cubic centimeter, and the removal of all

substances which retain bromine and therefore cause slight liberation of iodine permits the determination of small traces of iodine with a much higher degree of accuracy than before. For example, it has been found that talcum, even after boiling for 10 minutes, will retain bromine equivalent to as much as 0.08 cc. of 0.005 N thiosulfate. This amount of iodine is approximately that found as the normal iodine content of 100 cc. of blood, so that any results which have been obtained in the past with talcum are questionable, at least to within 0.05 to 0.08 cc. of 0.005 N thiosulfate. The method in detail as now employed in our laboratories is as follows:

The first step is the destruction of organic matter and the retention of the iodine as sodium iodide. This is accomplished by fusion with sodium hydroxide in a nickel crucible. In order to maintain a proper degree of temperature and to prevent loss of iodine by volatilization, the crucible is heated indirectly by placing inside a larger crucible, the bottom of which is covered with a layer of sand 0.5 cm. in thickness. The details of the construction of the heating apparatus have been described elsewhere (2). The supporting cylinder is 9.4 cm. in diameter and 30 cm. high; the cross bars which support the large crucible are 7.5 cm. from the top. The larger crucible is of iron and is 7.8 cm. in diameter. The smaller one is of pure nickel and is 5.9 cm. in diameter. The burner is preferably a 15.6 cm. (No. 3) Meker burner.

For the determination of iodine in thyroid preparations it is best to use not more than 0.5 gm. of material. Whether this is in the form of a dry powder, a solution, or a moist precipitate on a filter paper, the same procedure is carried out. The material is placed in a 5.9 cm. nickel crucible and moistened with a few drops of 30 per cent sodium hydroxide; 5 to 10 gm. of stick sodium hydroxide which has been broken into small pieces are added and the crucible is placed on a hot plate until the excess of water is evaporated and the contents have a thick, syrupy consistency. If but little organic matter is present, there is a tendency for spattering of fine drops during the evaporation of the excess water. If some organic substance is dissolved in the solution this spattering is prevented. A small amount of lactose is suitable and sufficient for this purpose.

For the fusion of the organic matter with the sodium hydroxide it is necessary to heat the bottom of the large crucible to a red heat. If the crucible is heated too much the fusion in the small crucible will creep up the sides and sodium hydroxide will volatilize with loss of iodine. If the large crucible is heated insufficiently the destruction of organic matter will not be complete. However, there is a wide range of temperature between the two limits and after a little experience no difficulty is encountered.

When the sodium hydroxide is first heated in the presence of water considerable foaming is produced. This, however, does not extend more than half way up the sides of the crucible. As the heating continues the foaming becomes less and after from 5 to 10 minutes the melt settles to the bottom. Bubbles continue to be given off for some time (5 minutes or so), depending on the nature of the organic matter.

When the melt has settled to the bottom and only a few bubbles of gas are being liberated, the small crucible is removed with crucible tongs and partially cooled by agitating the contents with a rotary motion. This will also remelt and carry to the bottom any particles of the fusion which have solidified on the cooler sides of the crucible.

5 to 10 mg. of potassium nitrate are now added. This oxidizes the remaining organic matter and causes a liberation of bubbles. If only a few bubbles appear, a second addition of from 5 to 10 mg. of potassium nitrate will not cause a further liberation of bubbles and the oxidation of the organic matter is complete. If the second addition of nitrate causes a further oxidation, repeated additions of from 5 to 10 mg. of the nitrate are made until no more bubbles of gas are produced by the addition of the nitrate. The melt is now poured into the shallow cover of the 5.9 crucible and allowed to cool.

The entire time required for the fusion is from 10 to 15 minutes. It is most convenient to use two crucible-supporting cylinders and to carry on two fusions at the same time.

When the melt and crucible are cool, they are placed in a beaker of from 600 to 800 cc. capacity and 125 to 150 cc. of water are added: The beaker is then placed on a hot plate. After the melt is dissolved it is transferred to a 500 cc. Erlenmeyer flask.

It should be a colorless, clear solution with a volume of about 200 cc. To the solution 5 cc. of 20 per cent sodium bisulfite and just two drops of a saturated water solution of methyl orange are added.¹ The solution is cooled by immersing the flask in cold running water. When it is cool, 85 per cent phosphoric acid is added by allowing the acid to run directly into the flask from a pipette or syphon having a small delivery tube. The flask is vigorously and constantly shaken with a rotary motion to expel the carbon dioxide. As the indicator begins to turn pink the neutralization is finished slowly, and the addition of acid is stopped at the first definite change of the indicator to pink. 5 cc. of 20 per cent phosphoric acid and a small piece of hard coal, about 0.5 cm. in diameter, are added. The volume is adjusted to about 250 cc. and the water is boiled on a hot plate for at least 10 minutes, and longer if necessary, until the volume of the solution is about 200 cc. After the flask has been cooled in water bromine is added and the solution shaken until the bromine imparts a distinctly yellow color. This is essential, as the addition of too little bromine will prevent the subsequent determination of iodine. The flask is again placed on a hot plate and the solution is boiled, the time when all visible bromine is expelled being noted. This will require about 3 minutes of actual boiling. The solution is boiled for just 5 minutes after it is colorless. It is then removed from the hot plate, a few crystals of salicylic acid are added, and the flask is immersed in cold water. The volume of the solution after boiling should not be less than 175 cc. as the high concentration of the salts makes the end-point less sharply defined.² 5 cc. of reduced 20 per cent phosphoric acid and about 1 gm. of pure potassium iodide crystals are added.

¹ The sulfite and bromine destroy the color of methyl orange if only two drops are added. If more than two drops are added the solution may retain a pink color.

² Experience has shown that practically all samples of distilled water take up small amounts of iodine. As this reducing action is destroyed by boiling with bromine this source of error is entirely controlled under the conditions of the method described above. However, a considerable error may result in the determination of iodine if any distilled water is added after the bromine has been boiled out of the solution.

The liberated iodine is now titrated with 0.005 N sodium thiosulfate.³ The titration is finished with the aid of the blue

³ The best strength of sodium thiosulfate for amounts of iodine ranging from 0.1 to 5 mg. is 0.005 N. The stability of the thiosulfate solution depends in large part on its manner of preparation. The most satisfactory method is to boil distilled water for at least 30 minutes leaving the final volume about 4 liters. 5.25 gm. of sodium thiosulfate crystals are added to about 1 liter of this boiled water and this solution is boiled for about 30 minutes. The solution is cooled and made to 4 liters with the boiled water and is protected from carbon dioxide by a sodium hydroxide tube. This solution must be restandardized frequently. A convenient method proposed by Hunter is to prepare a solution of potassium acid iodate which is equivalent to a known weight of iodine. The strength of any sample of thiosulfate is readily found by titrating the iodine liberated by the acid iodate solution, which retains its strength indefinitely. The iodine equivalent of the potassium iodate is found as follows:

Prepare a 0.1 N solution of potassium acid iodate, $\text{KIO}_3 \cdot \text{HIO}_3$, by dissolving 3.249 gm. of the salt in 1 liter of water. This solution diluted twenty times will be approximately 0.005 N. Dissolve a known weight of pure iodine (approximately 1 gm.) in 1 liter of water containing from 5 to 6 gm. of sodium hydroxide. Dilute this ten times. 1 cc. of this solution will contain 0.1 mg. of iodine. Measure 25 cc. of this solution into a 500 cc. flask and dilute to 200 cc.; add 10 cc. of 30 per cent sodium hydroxide; and neutralize as in the determination with 85 per cent phosphoric acid to a definite pink color with methyl orange. Add 5 cc. of 20 per cent phosphoric acid, a small piece of hard coal, 5 cc. of 20 per cent sodium bisulfite, place the flask on a hot plate, and boil for at least 10 minutes. Cool, add bromine, and boil as described in the determination. Add salicylic acid, cool, then add 5 cc. of 20 per cent reduced phosphoric acid, 1 gm. of potassium iodide crystals, and titrate the liberated iodine with approximately 0.005 N thiosulfate. This will establish the relation between "original iodine" and the 0.005 N thiosulfate, and from this the iodine equivalent of the potassium acid iodate can be found as follows:

Add a known volume, 10 or 15 cc., of the acid iodate solution to a 150 cc. flask. Add 0.25 gm. of potassium iodide crystals, five drops of a 20 per cent reduced phosphoric acid solution, and titrate with the thiosulfate, using starch at the end. When a small amount of iodic acid is in a solution which contains but a small amount of salts, the reaction with potassium iodide is retarded and the end-point of the titration with thiosulfate is uncertain. In the original method the volume of water present with the potassium acid iodate was about 150 cc. and to this sodium chloride was added in order to increase the distinctness of the end-point. It has been found that the salt is a source of error and that more accurate results are obtained by not diluting the iodate solution. The potassium iodide added should be reduced to a minimum, as large amounts will cause a pink-colored end-point instead of blue with starch.

starch-iodine color. For this a 0.5 per cent solution of soluble starch is recommended (3).

The most convenient procedure if a number of determinations are made each day is to use six or seven crucibles, each marked with a letter for identification. Each crucible has a corresponding 500 cc. Erlenmeyer flask marked with the same letter. The crucibles are used in rotation. Frequent blanks should be made on all reagents used, and the reduced phosphoric acid should be tested at intervals with potassium iodide.

Accuracy of the Results.

The following determinations were made with iodine in the form of potassium iodide added to water. Titrations were made with 0.005 N thiosulfate.

Amount found.			
1.0 mg. iodine added.	0.5 mg. iodine added.	0.3 mg. iodine added.	0.1 mg. iodine added.
mg.	mg.	mg.	mg.
1.008	0.501	0.299	0.102
1.008	0.500	0.300	0.102
1.000	0.501	0.302	0.101
1.000	0.502	0.302	0.101
1.000	0.503	0.299	0.102
1.000	0.502	0.298	0.105
1.004	0.504	0.299	
1.004	0.504	0.299	
1.001			
1.007			
1.006			
1.002			
1.004			
1.004			
1.007			
1.007			
1.000			
1.000			
1.000			
1.000			
1.000			
0.994			
0.994			
0.993			
0.993			

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DETERMINATION OF IODINE IN BLOOD AND IN ANIMAL TISSUES.

FOURTH PAPER.

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Although the refinements outlined in the previous paper permit the determination of minute amounts of iodine, the method cannot be applied directly with blood and tissues because the iodine content of 0.5 gm. or even 1 gm. of the material is much too small to be detected. However, the only additional requirement to the method is the destruction of a large amount of organic matter without loss of iodine. The first attempt was to hydrolyze the proteins of blood and tissue with 5 per cent sodium hydroxide in an autoclave at 200°. The solution was acidified and filtered. Attempts were then made to distill the iodine from the solution after the addition of an oxidizing agent. For this purpose chromic acid, copper, iron, and arsenic were tried, and it was found that although the iodine was liberated it was not quantitatively distilled.

The next attempt to destroy the organic matter was by means of a fusion with nitrate. This resulted in excessive heating, the organic matter frequently igniting. As this was always accompanied by loss of iodine, it was found impracticable to destroy the organic matter with oxidation.

Attempts were then made to remove the organic matter simply with a destructive distillation, and it was eventually shown that in the presence of about 3 gm. of sodium hydroxide for each 100 gm. of blood or tissue the water can be evaporated on a hot plate and the organic matter destroyed at a temperature between 300–400° without appreciable loss of iodine. The char is extracted with water. The solution is dark brown and still contains a

large amount of organic matter. Treatment of the solution of the char with barium hydroxide will remove much of the color, but iodine cannot be determined in this solution by oxidation with bromine, as high results are obtained and the end-point is confused by a pink color. For the destruction of the remaining organic matter a second fusion in a small crucible was found to be necessary. By treatment with barium hydroxide the sodium hydroxide which was originally present and which had been converted into carbonate by the first fusion is regenerated as sodium hydroxide. The excess of barium is removed by just sufficient sulfuric acid, leaving the solution still alkaline with sodium hydroxide. The solution, which has a volume of 400 or 500 cc. after treatment with barium, is evaporated to not more than from 15 to 20 cc., and placed in a small nickel crucible.

The water is driven off in a specially constructed hot air chamber protected from carbon dioxide. The residue in the small crucible is then again fused after adding about 5 gm. more of solid sodium hydroxide. This fusion is identical with that described in the previous article. The solution of the fusion melt is now treated in the same manner as for the determination of iodine previously described, and a quantitative determination of the iodine originally present in 100 gm. of tissue is obtained. It is apparent that the original charring of 100 gm. of tissue can be extracted with water, the sodium hydroxide regenerated with barium hydroxide, and a second 100 gm. of blood or tissue may be added to the filtrate. In this way there is almost no limit to the weight of material which may be treated.

One point of interest will be mentioned which was discovered during the earlier attempts to perfect the method. All traces of iodine may be precipitated from a slightly alkaline solution containing barium by boiling with a small amount of potassium permanganate and a few drops of alcohol. The iodine is carried down in the barium manganese precipitate, probably in the form of barium iodate, leaving the solution practically free from manganese, and entirely free from iodine. This fact, however, could not be utilized for the determination of iodine, as it was found extremely difficult to get the iodine back into solution from the precipitate. Boiling with sulfuric or sulfurous acid produces only a partial decomposition, much of the iodine remaining with the barium.

The method in detail for the determination of iodine is as follows: 100 cc. of blood, or 100 gm. of muscle or liver,¹ hair, skin, or bone, are placed in a nickel crucible of 500 cc. capacity. 10 cc. of a 30 per cent sodium hydroxide solution are added and the crucible is placed on a hot plate. After all water has evaporated, which requires about 40 minutes, the crucible is placed on a circular metal disc, a little larger in diameter than the bottom of the crucible, over a gas burner and inside a metal cylinder of the dimensions shown in Fig. 1. The flame is adjusted to such a height that all fumes have ceased to be thrown off at the end of not more than 12 minutes. No definite directions can be given for the destruction of the organic matter as each sample of material varies. In general, however, the contents of the crucible form a thick, tarry mass, which rises almost to the top during the first 2 or 3 minutes. The cover cannot be placed on the crucible until after the contents have subsided, which is usually at the end of 6 or 7 minutes. The crucible is covered as soon as possible, as more heat is thereby retained and the destruction accelerated. The best criterion for the finished fusion is the odor and the throwing off of fumes. The heating should be adjusted so that not more than 11 or 12 minutes are required to render the crucible odorless. The char will then have an iridescent black film over the top. It should be very dry and brittle. The crucible is allowed to cool. About 25 cc. of water are added, and the char which sticks very firmly to the crucible is scraped off. The char is ground with a pestle and is boiled in the crucible with about 50 cc. of water. The carbon is removed by filtration on a Buchner funnel, and is then returned to the crucible together with the filter paper and is again boiled with about 30 cc. of water containing 1 to 2 cc. of 50 per cent sulfuric acid. The residue is filtered on a Buchner funnel and the filtrate added to the main portion. To this solution in a beaker 18 gm. of crystalline

¹ When muscle or liver, or other tissue, is used it is essential to make a homogeneous solution in the nickel crucible with sodium hydroxide before the water is all evaporated off. If the material coagulates in large lumps it is sometimes necessary to evaporate down with water on the hot plate two or three times in order to dissolve all the large gelatinous lumps. As soon as complete solution is secured the material can be treated as blood and the water is all evaporated off.

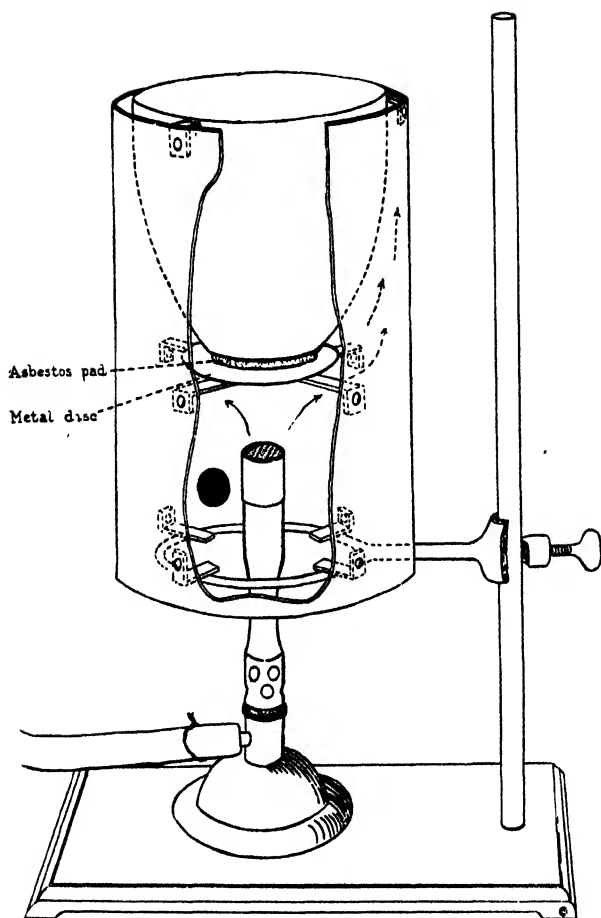


FIG. 1. Cross section of cylinder showing 500 cc. crucible resting on a small asbestos pad supported by a metal disc a trifle larger than the bottom of the crucible. The diameter of the cylinder is 13 cm., of the crucible 10 cm., and of the disc 8.5 cm. The height of the cylinder is 19 cm. A Meker burner 16 cm. high is used.

barium hydroxide² are added. The solution is filtered into a suction flask through the Buchner funnel just previously used and still holding the residue of the char. Sufficient sulfuric acid is added to remove all barium, and the solution is again filtered on another Buchner funnel, through a pad of kaolin. The volume at this point is about 400 cc. The solution is placed in a 600 or 800 cc. beaker, a small piece of hard coal is added, and the water is evaporated by rapid boiling on a hot plate. When the solu-

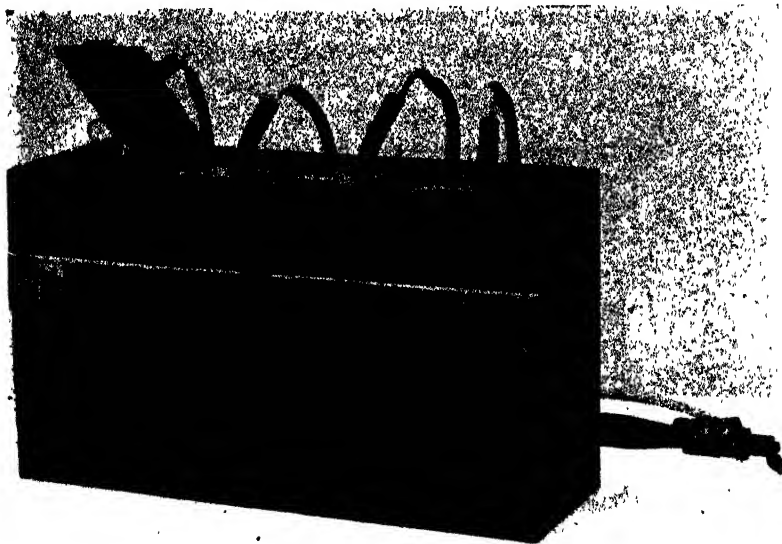


FIG. 2. Hot air oven used to remove water from the small crucible and at the same time protect the sodium hydroxide from carbon dioxide.

² The barium hydroxide is prepared from technical commercial barium hydroxide which is twice purified by solution in boiling hot water, filtration through a Buchner funnel, and crystallization of the barium hydroxide from the filtrate by cooling to 15 or 20°. The barium hydroxide should be tested for iodine by precipitating about 100 gm. of the material with carbon dioxide from an aqueous solution after the addition of about 3 gm. of sodium hydroxide. The barium carbonate is removed by filtration, the sodium carbonate in the filtrate is neutralized with phosphoric acid, and the regular method for the determination of iodine carried out.

tion has been reduced to 15 or 20 cc. it is transferred to a nickel crucible of 100 cc. capacity. All but the last trace of water is removed by heating in the hot air chamber (Figs. 2 and 3). The fusion is then carried out, as described in the preceding

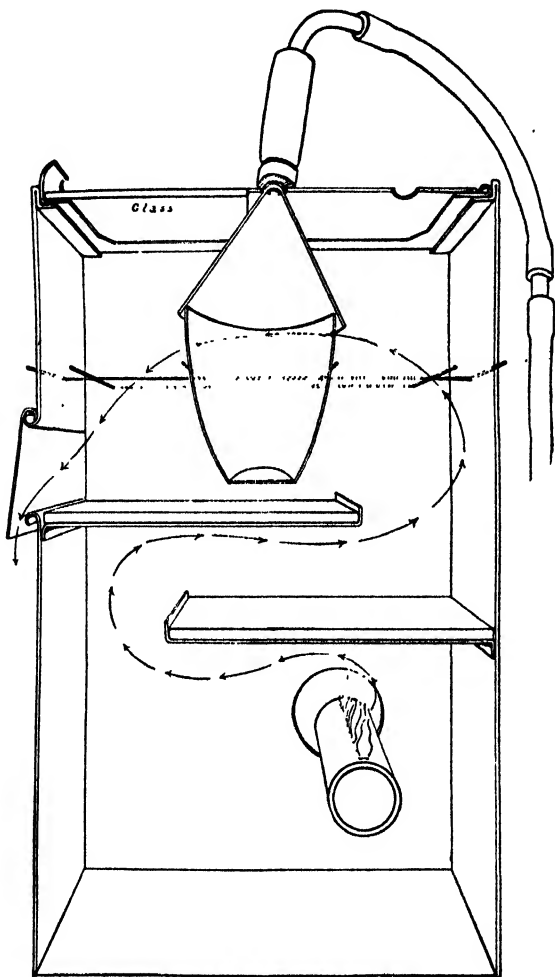


FIG. 3. Cross section of oven showing crucible supported by wires. The temperature of the oven is 180°C . A rapid current of air is blown over the surface of the crucible by means of the inverted funnel.

article. In order to minimize the possibility of securing high results, it is very important to carry out the second fusion, using as little nitrate as possible. The small crucible contains a large percentage of carbonate, which forms during the evaporation of the water, so that the best conditions for a satisfactory fusion are obtained by adding about 4 or 5 gm. of solid sodium hydroxide just prior to the fusion. The organic matter should then be allowed to decompose without the aid of any nitrate until all active liberation of gas has ceased. The entire amount of nitrate added can then be reduced to a few milligrams. Not more than 4 or 5 mg. should be added at any one time. The temperature should be such that the fusion proceeds rapidly, but not so high as to cause the sodium hydroxide to creep up the sides of the crucible. The solution of the fusion melt must be perfectly clear. If it is the least turbid it should be filtered on a suction funnel through a layer of kaolin. Methyl orange is added to the solution which is then acidified and the iodine determined as described in the preceding paper. It is of the highest importance to make frequent tests on all the solutions used. A perfect blank should be secured which will stay colorless at least 15 minutes after the addition of starch and potassium iodide. The Buchner funnels and flasks should not be used for any other work. The filter paper and all utensils should be tested for the presence of the minutest amounts of iodine. The work should be carried out in a room in which iodine is not used and care must be exercised to prevent contamination by potassium iodide used in the titration.

Accuracy of Results.

In order to show the accuracy of results after charring 100 gm. of the material and determining the iodine as described, the method was carried out with blood. 100 cc. of blood were charred in a 500 cc. crucible and the water extract was treated with barium hydroxide, evaporated to small volume, and the residue again fused in a small crucible. Iodine was then determined in the water solution of the fused material. The results obtained are given in Table I.

In order to show that added iodine can be determined by this method in the presence of the products from 100 cc. of blood, iodine as potassium iodide was added to the water solution after charring and fusing 100 cc. of blood (Table II). The method was then carried out as described.

TABLE I.

Experiment No.	Iodine content of 100 cc. of blood.
	<i>mg.</i>
1	0.013
2	0.014
3	0.015
4	0.016
5	0.017
6	0.016
7	0.010
8	0.013
9	0.013
10	0.013
11	0.014
12	0.011
13	0.010
14	0.011
15	0.010
16	0.010
17	0.011
18	0.014
19	0.011
20	0.012
21	0.016
22	0.014
23	0.013
Average.....	0.013

The difference between the amount added and the amount found averaged 0.013 mg. of the iodine, which is the average iodine content found for 100 cc. of blood.

The iodine was then added as potassium iodide to the blood before it was charred and all steps of the method were carried out as described. The results obtained are given in Table III. The total amount of iodine present is the sum of the added iodine

and 0.013 mg. of iodine, which is the average amount found in 100 cc. of blood.

The difference between the total iodine present and the amount found in Table III averages about 2.5 to 3 per cent of the total amount present. When the iodine is added after the blood has been charred, there is no loss of iodine due to any of the steps in the method. The only actual loss of iodine occurs during the charring of the blood. By adding different amounts of iodine to the blood it has been shown that this is not an absolute loss,

TABLE II.

Iodine added.	Iodine found.	Difference.
<i>mg.</i>	<i>mg.</i>	<i>mg.</i>
1.003	1.016	0.013
1.003	1.015	0.012
1.003	1.017	0.014
1.003	1.012	0.009
1.007	1.028	0.021
1.002	1.017	0.015
1.002	1.017	0.015
1.002	1.017	0.015
1.002	1.017	0.015
1.002	1.017	0.015
1.007	1.011	0.004
1.007	1.011	0.004
1.001	1.025	0.024
1.001	1.012	0.011
1.001	1.018	0.017
1.001	1.005	0.004
Average		0.013

but a percentage loss. The same percentage loss occurred when 1, 0.5, 0.3, or 0.1 mg. was used, and, since no greater loss could occur under the conditions for the iodine determined in 100 cc. of blood without the addition of more iodine, the results may be regarded as quantitative except for the same percentage loss, that is, no more than 3 per cent. Although this is a serious loss for a quantitative method, in this particular case the total amount is so small that the 3 per cent loss due to the first step in the method is actually less than can be read on the burette with

TABLE III.

Total amount of iodine in 100 cc. blood.	Iodine found.	Difference.	Average loss.
<i>mg.</i>	<i>mg.</i>	<i>mg.</i>	<i>per cent of total iodine</i>
1.021	1.000	-0.021	
1.018	0.990	-0.028	
1.018	0.995	-0.023	
1.021	1.006	-0.015	
1.016	1.000	-0.016	
1.013	1.000	-0.013	
1.018	0.984	-0.034	
1.018	0.978	-0.040	
1.018	0.980	-0.038	
1.018	0.989	-0.029	
1.018	0.993	-0.025	
1.018	0.976	-0.042	
1.018	1.002	-0.016	
1.018	0.992	-0.026	
1.019	0.984	-0.035	
1.019	0.999	-0.020	
1.016	0.988	-0.028	
1.016	1.011	-0.005	
1.016	0.989	-0.027	2.5
0.514	0.508	-0.006	
0.513	0.495	-0.018	
0.515	0.493	-0.022	
0.516	0.509	-0.007	
0.516	0.513	-0.003	2.2
0.313	0.299	-0.014	
0.312	0.299	-0.013	
0.316	0.312	-0.004	
0.316	0.306	-0.010	
0.312	0.307	-0.005	2.9
0.115	0.111	-0.004	
0.115	0.116	-0.001	
0.115	0.111	-0.004	
0.115	0.107	-0.008	
0.115	0.111	-0.004	
0.118	0.116	-0.002	3.0

accuracy. For normal blood the amount would be 0.0004 mg. of iodine or 0.004 cc. of 0.005 N thiosulfate.

FORMATION OF THE GUM, LEVAN, BY MOLD SPORES.*

I. IDENTIFICATION AND QUANTITATIVE DETERMINATION.

II. MODE OF FORMATION AND INFLUENCE OF REACTION.

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I. Identification and Quantitative Determination.

The formation of the gum, levan, during the bacterial decomposition of sugar has been noted by Greig-Smith and Steel (1) and Owen (2). The former and Taggart (3) agree in the identification of chemical and physical properties of this bacterial gum called levan. In a consideration of the microbiological agencies responsible for sugar deterioration we have found that molds are by far the most dangerous single group of microorganisms normally occurring in sugars of all descriptions (4). However, in establishing the fact that mold spores contain enzymes and can therefore cause the inversion of sucrose without germination or growth, it is also noteworthy to observe that mold spores contain an enzyme which can produce gum in sterile sugar solutions (5) of 10 and 20 per cent concentration. In order to identify this gum the following procedure was employed.

Identification of Levan.

A pure pedigreed culture of *Aspergillus sydowi* Bainier was used to seed a large number of Petri dishes containing Kopeloff's agar (4). After the spores had developed in profusion they were floated off the plates with sterile distilled water onto a sterile filter paper (Whatman No. 4) and washed thoroughly (about 100

* Read at the St. Louis meeting of the Sugar Division of the American Chemical Society, April 15, 1920.

cc. of sterile distilled water per plate being used). The mold spores were washed into a sterile flask, 10 per cent of chloroform was added, and the suspension heated to 62.5°C. for 1 hour. The suspension was thoroughly ground with sterile sand and then added to 500 cc. portions of sterile 10 per cent sugar solution and incubated at 40°C. for 10 days. The solutions were shaken frequently and found to be sterile on plating out at the end of this period. 10 cc. of the sugar solution from control flasks uninoculated, when made up to 50 cc. volume, gave a single polarization of 13.2°V, while 10 cc. of the gum solution similarly diluted with alcohol gave a single polarization of 5.3.

The supernatant gum solution was then siphoned from each flask without disturbing the spore residue, which was discarded. Five volumes of 95 per cent ethyl alcohol were added to the gum solution which had been made alkaline with NaOH, the solutions being shaken thoroughly at frequent intervals and permitted to stand over night at room temperature. The alcoholic super-

TABLE I.
Chemical Composition of Levan Produced by Mold Spores.

Rotation.	Moisture.	Ash.	Hydrolysis.	Melting point.
	<i>per cent</i>	<i>per cent</i>		<i>°C</i>
-40.9°	0.17	0.16	-87.3 to -90.0	200

natant liquid was removed and the precipitated gum thoroughly washed with successive portions of alcohol. The precipitate was then dissolved in the least possible amount of cold sterile distilled water and shaken thoroughly in a shaking machine for 4 hours. Again the gum was precipitated by alcohol in the manner described above and the process repeated several times until a white flocculent precipitate was obtained. This was partially dried on filter paper and finally transferred to an unglazed porcelain plate where it remained for 18 hours at 20°C. The dry gum was then powdered and used for the determinations described below.

The specific rotation of this gum was about -40° in a 0.25 per cent solution, as may be seen in Table I.

The moisture content was 0.17 per cent, and ash 0.16 per cent. After hydrolysis with concentrated hydrochloric acid the specific

rotation was about -87 to -90° , which coincides with the results obtained by Greig-Smith and Steel (1) and Taggart (3) and indicates that the gum hydrolyzes quantitatively into levulose. The melting point was not sharply defined but occurred at about 200°C ., when the gum coalesced and puffed, rising sharply in the capillary tube.

TABLE II.
Effect of Reagents on Levan.

Treatment.	Result.
Oxidation with concentrated nitric acid, boiling.....	Oxalic acid.
Cold water.....	Soluble.
Hot water solution after cooling.....	Mucilaginous.
Prolonged heating at 100°	Unchanged.
Acid hydrolysis.....	Levulose.
Baryta.....	Precipitate.
Lime-water.....	No precipitate.
Milk of lime.....	Precipitate.
Strontium.....	"
Lead subacetate.....	"
Ammonium lead acetate.....	"
Litharge, cold.....	Not dissolved.
Fehling's solution.....	" reduced.
Ammoniacal mercuric nitrate.....	" "
Iodine.....	No blue.
Cuprammonia.....	Dissolves (does not deposit on standing).
Copper sulfate.....	Precipitate.
Ferric chloride.....	No precipitate.
Tannic acid.....	" "
Acid nitrate mercuric.....	" "

The dry gum is light yellowish gray giving a blue-gray opaque solution with water. It does not separate from semisolution when allowed to stand for periods of time, or when centrifuged. The effects of various reagents are included in Table II.

With two exceptions, namely precipitation by copper sulfate and lead subacetate, which is probably due to some impurities in the small amount of ash, these results coincide with the same data presented by Greig-Smith and Steel (1) and Taggart (3), and we are therefore led to conclude that the gum under con-

sideration which is formed by the enzymes in mold spores is none other than levan.

Previously we have noted the formation of levan in sugar solutions of varying concentration (5) and the data in Table III are further corroborative of the fact that the enzymes in mold spores causing inversion and levan production are active in highly concentrated sugar solutions, as, for example, 55 per cent in this instance. (All data in this and succeeding tables represent the average of closely agreeing triplicate determinations, unless otherwise stated).

TABLE III
Formation of Levan in 55 Per Cent Sugar Solutions.

Inoculum.	Single polarization.	Reducing sugars.	Gum.
		<i>per cent</i>	<i>per cent</i>
Control	55.1	2.29	
Mold spores.....	51.7	4.63	1.54

Determination of True Sucrose in the Presence of Gum.

It has been a matter of universal experience that the presence of a gum such as levan makes the polarization of a sugar solution very difficult and, furthermore, renders both single polarization and Clerget liable to errors of considerable magnitude, the former generally giving a lower value and the latter a higher value than that of the sucrose actually present. In making single polarizations of sugar solutions where levan is present, it has been our custom, wherever necessary, to remove the levan by precipitation with alcohol. However, even this method fails to give the true content of sucrose, and therefore it was necessary to develop some more adequate means of making this determination, the details of which follow.

Since the Clerget method involves a minus reading and is based on the use of hydrochloric acid, which has been shown to hydrolyze the gum to levulose, it will readily be seen that the reading will be still further magnified in a negative direction. Therefore, it was necessary to employ a method which would not affect the gum, but would give the true sucrose content. The

invertase method of Hudson (6) was found to fulfill these requirements.¹

A strong invertase solution was prepared by breaking up 5 pounds of Fleischmann's yeast in a mortar, placing it in a wide mouthed 10 liter bottle with ground glass stopper, adding 125 cc. of c.p. toluene (which is slightly more than the amount recommended by Hudson, while also omitting the addition of water), and keeping it at 20°C. On each day following, a portion of the liquefied mass was filtered and 5 cc. of the extract were added to 95 cc. of a 10 per cent sugar solution. Two drops of glacial acetic acid were added to both the check flasks containing 100 cc. of the sugar solution and the treated solution and held at 30°C. (Both the check flask and that containing 95 cc. of sugar solution as well as the yeast extract were held at 30°C. for 10 to 15 minutes until the contents attained the constant temperature before addition of the yeast extract.) The initial time was noted and polariscope readings were made every minute until one-half of the sucrose was inverted. The 1st day following the addition of toluene to the yeast the extract took 10.5 minutes to reduce the sucrose content one-half; the 2nd day 6.7 minutes were required; the 3rd day 5.6 minutes; the 4th day 4.3 minutes; and the 5th day 4.2 minutes. After the 4th day the bulk of yeast was placed on a large filter paper and the filtrate caught in a sterile flask containing 25 cc. of toluene. By permitting the filtrate to drip into the toluene and keeping the mouth of the receiving flask filled with cotton, the most favorable conditions of asepsis were obtained. Neutral lead acetate was added to the filtrate in a quantity sufficient to insure complete precipitation, and the solution centrifuged and decanted. This was again tested with neutral lead acetate and centrifuged in sterile tubes, the procedure being repeated until no precipitate formed. The very slight excess of neutral lead acetate was removed in a similar manner by the addition of 2 N potassium oxalate, centrifuging, and decanting. The solution was covered with a layer of toluene, then dialyzed in a fish skin membrane against running tap water for 2 days, and finally centrifuged and decanted. The invertase solution thus prepared was covered with a layer of toluene and kept in a sterile, ground glass-stoppered bottle in the refrigerator. It was active enough to invert completely a 10 per cent sugar solution in less than 20 hours at room temperature. In order to compare the efficiency of the invertase solution thus prepared with the Clerget method of hydrochloric acid inversion, several samples of standard granulated (refined) sugar, cane syrup, and 10 per cent sugar solutions were used, the latter with and without the addition of levan. Normal weights (26 gm.) of the materials under consideration were weighed out and made up to 100 cc. For the Clerget determinations 25 cc. of distilled water were added to 50 cc. of solution in a 100 cc. flask,

¹ This procedure was suggested by Assistant Director W. G. Taggart, to whom we are indebted for continued and invaluable assistance.

25 cc. of water added, then 5 cc. of concentrated hydrochloric acid, the solution was heated to 67-69°C. in 3 minutes, held at 69°C. for an additional 7 minutes, then cooled in an ice bath to a temperature several degrees below that of the room, made up to the mark, and polarized at the same temperature as the solutions for single polarization. For the invertase method 5 cc. of invertase were added to 50 cc. of solution made very slightly acid with 10 per cent acetic acid, distilled water was added up to the mark, 1 cc. of toluene added, and the flasks were covered with a watch-crystal and incubated at room temperature for 22 hours.

It will be seen from the data in Table IV that the results obtained for refined sugar by the invertase and Clerget methods agree very closely within the limits of experimental error. Only

TABLE IV.
Comparison of Clerget and Invertase Methods.

Solutions.	Sucrose.		Gum.
	Clerget method.	Invertase method.	
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
1. Refined sugar.....	10.66	10.67	
2. " "	10.59	10.51	
3. " "	10.59	10.53	
Cane syrup.....	43.47	43.20	
1.5 per cent levan in 10 per cent sugar solution.....	11.26	10.17	1.38
0.59 per cent levan in 10 per cent sugar solution.....	11.00	10.58	0.53
0.33 per cent levan in 10 per cent sugar solution.....	10.89	10.57	0.40

the averages of closely agreeing duplicate determinations were recorded. As might be expected there is a slight discrepancy in the case of cane syrup. This experiment was repeated with similar results.

Polariscope Determination of Levan.

It is of special interest to note that in addition to applying the invertase method to the determination of sucrose where gum is present, we have here likewise developed a method for the determination of the amount of gum present. In other words, we

have two equations, the one for Clerget or acid inversion, the other for invertase, the difference representing the transformation of gum to levulose. Thus for acid and invertase inversion the following graphic representation may be made of the polariscopic value of a sugar solution containing gum as follows:

Solution contains.	Levorotary.	Dextrorotary.
(a) <i>Acid inversion:</i>		
Before inversion.	Levulose + gum.	Sucrose + dextrose.
After "	Levulose + gum as levulose + $\frac{1}{2}$ su- crose to levulose.	$\frac{1}{2}$ Sucrose to dextrose + dextrose.
(b) <i>Invertase inversion:</i>		
Before inversion.....	Levulose + gum.	Sucrose + dextrose.
After "	Levulose + gum + $\frac{1}{2}$ sucrose to levu- lose.	$\frac{1}{2}$ Sucrose to dextrose + dextrose.

Therefore $a - b = \text{gum to levulose}$. Since we know that the specific rotation of levan is -40 and that of *d*-fructose is -92.5 , then the difference caused by hydrolysis of the levan is -52.5 . Since the specific rotation of sucrose is 66.5 , for every per cent of gum in the solution, we have a change in rotation as follows,

$$\frac{66.5}{52.5} = 1.27.$$

Now the difference in sucrose (as may be seen in Table IV) determined by the Clerget and invertase methods for 1.5 per cent levan in a sugar solution is $11.26 - 10.17$ or 1.09 . Therefore the per cent of gum present is 1.27×1.09 or 1.38 . This is only 0.12 below the theoretical recovery. Similar results were found where smaller amounts of gum were present.

Thus an adequate method has been established for the quantitative determination of gum, but one which is more reliable for larger rather than smaller amounts of gum in sucrose solution.

SUMMARY.

1. Mold spores (*Aspergillus sydowi* Bainier) contain an enzyme capable of forming gum in sucrose solutions of all concentrations up to the saturation point.

2. The specific rotation of the pure gum was found to be -40 , and the melting point about 200°C . Upon hydrolysis levulose was formed.

3. This gum is *levan*, since its chemical and physical properties are identical with those described in the bacterial decomposition of sucrose.

4. The invertase method has been successfully applied in the determination of true sucrose in the presence of gum.

5. Levan may be quantitatively determined polariscopically by using a combination of the Clerget and invertase methods.

II. Mode of Formation and Influence of Reaction.

In Part I we have discussed the identification and quantitative determination of levan. Perhaps the most baffling problem involving the presence of levan in sugar solutions is that concerned with its mode of formation. In an endeavor to throw some light upon this question the following experiments were conducted. 50 cc. of sucrose solutions of varying concentration with and without the addition of c. p. dextrose and levulose were inoculated with 10 cc. of mold spores with and without the addition of 2 cc. of invertase (the latter used to furnish an abundant supply of nascent dextrose and levulose). Sterile distilled water was added to the controls, etc., in such a way as to have all the solutions of equal volume. The flasks, after 1 week's incubation at 45°C ., were analyzed for acidity, sucrose by single polarization, reducing sugars (volumetric), and gum by precipitation with alcohol in alkaline solution, and weighing upon tared filter papers.

While there is considerable variation in the results presented in Tables V to VII, nevertheless certain generalizations may be made. In the first place it may be seen in Table V where there were present 34,000 spores per cc. of solution, that there is a direct relation between the amount of sucrose present and the quantity of levan formed; *i.e.*, the largest amount of gum where mold spores are present is 0.19 per cent in 10 per cent sucrose alone. In 5 per cent sucrose the gum drops to 0.13 per cent and in 1 per cent sucrose the gum is only 0.08 per cent. Similarly in Table VI, where there were 47,000 spores per cc. of solution, the more sucrose present the greater is the gum formation. This is

in agreement with Owen's (2) conclusions based on the formation of levan by bacteria. The increase in reducing sugars (dextrose and levulose, both c. p.) bears an inverse relation to the gum formation when only spores are present. On the other hand, when invertase has been added to the spores the largest levan production occurs where there is a greater supply of reducing sugars. This may simply be a corollary to the fact that the greatest amount of reducing sugars occurs where the sucrose content is highest. In this connection it might be well to consider the differences in acidity as measured in terms of 0.1 N NaOH and in Tables VI and IX in pH. While as a rule there is an increase in acidity where invertase has been added to mold spores this does not appear to be of sufficient magnitude to account for the differences obtained. It will be observed that when the polarization of sugar solutions inoculated with invertase and mold spores is compared with invertase alone almost invariably the latter is higher than the former, and this despite the fact that an inoculation of mold spores causes a reduction in polarizations when compared with the controls, because some of the nascent reducing sugars from sucrose are used for gum formation. An explanation may be found in the fact that the true acidity of the solutions containing invertase is greater than where mold spores have been added, and similarly the true acidity of the control solutions was generally higher than where mold spores had been added. This was obscured in the method of titrating 15 cc. of the solution with 0.1 N NaOH using phenolphthalein as an indicator, for in such cases the apparent acidity indicated was greater in the case of an inoculation with mold spores than in the controls. However, by adopting the methods and procedure outlined by Clark and Lubs (7), in their notable application of physical chemistry to bacteriology, it was found that the pH values obtained made certain important facts evident; namely, that the pH values of the mold spore inoculation indicated the presence of less true acidity than was to be found in the controls. Consequently it is to be expected that the presence of mold spores would tend to reduce the acidity present where invertase was used. This condition also accounts for the fact that in the solutions containing invertase and mold spores there was less gum formed than where mold spores alone were used, and gum formation is

best aided by the absence of acidity. It would be of interest in this connection to compare spore suspensions of many fungi with a view to ascertaining the pH values, and this study will be carried out in the near future.

TABLE V.

Formation of Levan by Mold Spores in Sugar Solutions of Varying Concentrations.

Inoculum.	Single polar- ization.	Reducing sugars.	Gum.	Titratable acidity of 5 cc.
Solution A. 10 per cent sucrose.				
		per cent	per cent	cc. 0.1 N NaOH
Control.....	7.5	1.26	0	0.02
Mold spores.....	6.5	1.47	0.19	0.02
Invertase.....	-2.8	10.00	0	0.10
Spores and invertase....	-1.1	10.00	0.06	0.09
Solution B. 5 per cent sucrose + 2.5 per cent each of dextrose and levulose.				
Control.....	2.4	5.00	0	0.07
Mold spores.....	2.7	5.88	0.13	0.07
Invertase.....	-2.5	9.52	0	0.19
Spores and invertase.....	-1.0	8.69	0.04	0.16
Solution C. 1 per cent sucrose + 4.5 per cent each of dextrose and levulose.				
Control.....	-1.6	8.33	0	0.13
Mold spores.....	-1.7	8.69	0.08	0.13
Invertase.....	-2.3	8.69	0	0.30
Spores and invertase.....	-1.1	7.57	0.04	0.16
Solution D. 5 per cent dextrose and 5 per cent levulose.				
Control.....	-2.0	8.69	0	0.17
Mold spores.....	-2.1	8.69	0.12	0.20
Invertase.....	-2.0	8.69	0	0
Spores and invertase.....	-0.6	7.81	0.11	0.14

It will be seen from Tables V to VII that in the absence of sucrose in solutions containing 5 per cent each of c. p. dextrose and levulose there has been as much gum formed as in solutions containing 1 per cent of sucrose and 4.5 per cent each of dextrose

and levulose. These data contradict those of previous investigators in that no formation of gum has heretofore been recorded where c. p. dextrose and levulose have been used without the addition of sucrose. In order to test these Merck chemicals for

TABLE VI.

Formation of Levan by Mold Spores in Sugar Solutions of Varying Concentrations.

Inoculum.	Single polarization.	Loss, single polarization	Reducing sugars	Gain, reducing sugars.	Gum.	Titration acidity of 15 cc	Reaction.
Solution A.							
			per cent	per cent	per cent	cc 0.6 N NaOH	pH
Control.....	8.0		0.17		0	0.30	7.1
Mold spores.....	5.9	2.1	2.14	1.97	0.16	0.06	7.0
Invertase.....	-2.2	10.2	8.47	8.30	0	0.35	5.1
Spores and invertase.....	-0.8	8.8	8.58	8.41	0.08	0.32	6.7
Solution B.							
Control.....	2.4		4.43		0	0.28	4.7
Mold spores.....	1.8	0.6	5.77	1.34	0.08	0.42	6.7
Invertase.....	-0.5	2.9	8.33	3.90	0	0.45	4.9
Spores and invertase.....	0.6	1.8	7.69	3.26	*	0.34	6.5
Solution C.							
Control.....	-0.9		7.32		0	0.40	4.6
Mold spores.....	-0.2		7.51	0.19	*	0.62	6.2
Invertase.....	-1.6	0.7	8.33	1.01	0	0.30	6.2
Spores and invertase.....	-0.5	0.4	7.69	0.37	*	0.48	6.3
Solution D.							
Control.....	-1.8		7.69		0	0.70	4.7
Mold spores.....	-0.5		7.69		*	0.64	6.1
Invertase.....	-1.8		7.69		0	0.70	5.0
Spores and invertase.....	-0.5		7.32		0.01	0.61	6.2

* Negligible amounts.

the presence of sucrose, normal weights of a 10 per cent solution were taken for single polarization and Clerget at room temperature (25-30°C.) for 20 hours. The solutions were brought to neutrality with strong NaOH and acidified with two drops of

10 per cent acetic acid before making up to the mark. The results obtained proved that these sugars were entirely free from sucrose which might influence gum formation. Such evidence would seem to indicate that the formation of gum from sucrose requires the intermediate formation of reducing sugars, whether in the nascent state or otherwise. A further discussion of this conclusion will be considered in the experiments which follow, concerning the reaction of the medium.

TABLE VII.

Formation of Levan by Mold Spores in Sugar Solutions of Varying Concentrations.

Inoculum.	1 per cent sucrose + 4.5 per cent dextrose + 4.5 per cent levulose.				5 per cent dextrose + 5 per cent levulose.			
	Single polarization.	Loss, single polarization.	Reducing sugars.	Gum.	Single polarization.	Loss, single polarization.	Reducing sugars.	Gum.
			per cent	per cent			per cent	per cent
Control.....	-1.4		8.69	0	-2.0		8.96	0
Mold spores.....	-0.3	-1.1	8.82	0.07	-0.5	-1.5	9.09	0.06
Spores and invertase.....	-0.5	-0.9	8.89	0.06	-0.5	-1.5	8.96	0.06

Influence of Reaction on the Formation of Gum.

In order to approach the study of the formation of levan from still another angle, sucrose solutions with and without the addition of invertase were treated with varying amounts of alkali. Since an excess of hydroxyl ions will prevent the enzyme, invertase, from being active, it was hoped that a point of alkalinity might be obtained where the invertase would be inactivated but the levanase would perhaps function in the formation of gum, so that the fact could be established whether or not invert sugar is necessary for the formation of levan. Sterile 0.1 N NaOH was first added at the rate of 2, 3, and 4 cc. to 50 cc. of 10 per cent sugar solution, untreated, inoculated with mold spores plus 2 cc. of invertase.

The results of 1 week's incubation at 43°C., are presented in Table VIII from which it appears evident that with 2 cc. of 0.1 N alkali there is practically no difference in the per cent of gum

formed whether invertase is present or absent, while with 3 cc. of alkali there is a marked increase in gum formation in the presence of invertase. A further increase in alkalinity, namely 4 cc., gives similar results in lesser amount. These data indicate that the reaction of the medium is a limiting factor in the formation of levan from sucrose by mold spores, in so far as it influences invertase activity. It is quite evident that this activity is extremely sensitive to slight changes in reaction and becomes inhibited by any appreciable concentration of acidity or alkalinity.

TABLE VIII.

Formation of Levan by Mold Spores in Sugar Solutions Receiving Alkali.

Inoculum.	Titrateable acidity of 5 cc.	Single polariza- tion	Reducing sugars.	Gum.
Addition 2 cc. of 0.1 N NaOH.				
	cc. 0.1 N NaOH		per cent	per cent
Control.....	0.02	6.4	1.49	0
Mold spores.....	0.02	5.9	1.92	0.08
Spores and invertase.....	0.05	-0.5	8.33	0.09
Addition 3 cc. of 0.1 N NaOH.				
Control.....	0.01	6.4	1.09	0
Mold spores.....	0.01	6.0	1.79	0.09
Spores and invertase.....	0.03	4.5	3.03	0.22
Addition 4 cc. of 0.1 N NaOH.				
Control.....	0.02	6.4	1.11	0
Mold spores.....	0.01	5.3	1.12	0.07
Spores and invertase.....	0.03	4.4	3.23	0.19

The use of invertase in the above solutions was to insure an adequate source of *nascent* dextrose and levulose by the means of an agent which would not otherwise affect the biological processes involved. Naturally, there was always present an adequate supply of reducing sugars. Since the maximum gum formation occurs in the presence of invertase (with 3 cc. of alkali) and where there is actually a smaller amount of reducing sugars formed, it is apparent that the most favorable source of gum formation is the nascent dextrose and levulose formed from sucrose by invertase.

In Table IX similar data are presented employing a wider range of alkalinity varying from 0.3 to 2.0 cc. of *N* NaOH per 50 cc. of 10 per cent sucrose solution. While these results are quite variable due to a light inoculation of 24,000 spores per cc. of solution, nevertheless there again seems to be evidence to the effect that gum formation goes forward most favorably in the presence of invertase which is responsible for the presence of nascent dextrose and levulose. However, several of these solutions were contaminated with bacteria, which were probably

TABLE IX.

Effect of Alkalinity on Formation of Levan by Mold Spores.

N alkali. cc.	Control.			Mold spores.				Mold spores and invertase.			
	Single polar- ization.	Reducing sug- ars.	pH	Single polar- ization.	Reducing sug- ars.	Gum.	pH	Single polar- ization.	Reducing sug- ars.	Gum.	pH
0.3	8.1	0.15	7.3	8.1	1.67	0.2	7.3	-0.5	8.33	0.39†	7.0
0.4	9.0	0.16	6.8	8.8	0.49	*	7.3	1.0	7.18	0.46†	6.7
0.5	8.8	0.18	7.5	8.8	0.36	0.5	7.9	0	8.46	0.09	7.1
0.6	8.8	0.20	7.1	9.1	0.31	*	7.6	0.6	8.11	0.34	7.1
0.7	8.3	0.17	7.3	8.8	0.20	*	7.5	0.8	7.03	0.22†	6.6
0.8	8.3	0.08	7.6	8.3	0.18	0.2	7.8	2.0	6.06	0.58†	6.9
1.0	8.3	0.10	7.9	8.9	0.06	*	8.1	1.2	7.14	0	7.1
1.5	8.4	0.07	8.1	8.5	0.10	*	8.3	8.4	0.01	0.01	7.6
2.0	8.3	0.05	8.3	8.6	0.06	0.04	8.3	8.6	0.06	0	7.3

* Negligible amount.

† Bacterial contamination.

responsible for some increase in gum formation. A point of considerable interest in this experiment is that the pH values of the solutions containing mold spores were higher than the control flasks, showing again that the reaction of that inoculum tends to make the reaction of one medium more alkaline, while the addition of invertase invariably increases the acidity. It will be observed that the maximum gum formation occurred with the addition of 5 cc. of 0.1 *N* alkali or at a pH value of 7.1 which is practically true neutrality (7.0 representing neutrality). Thus we are led to believe that the maximum gum formation occurs

where nascent dextrose and levulose are available and the reaction of the medium is practically neutral.

The influence of marked changes in alkalinity of the medium is shown in Table X, where there were 108,000 spores per cc. of solution where from 0.6 to 6.0 cc. of N NaOH have been added to 70 cc. of 10 per cent sucrose solution. Here again the maximum gum formation occurs in the presence of nascent dextrose and levulose (invertase added) where the reaction is nearly neutral. In fact three times as much gum is formed as where invertase has not been added. An increase in alkalinity causes an inhibition in invertase activity (as seen by the amount of reducing sugars present), and also a reduction in gum formation.

TABLE X.
Effect of Alkalinity on Formation of Levan by Mold Spores.

N alkali. cc	Control.			Mold spores.			Spores and invertase.		
	Single polariza- tion.	Reduc- ing sugars.	Gum	Single polariza- tion.	Reduc- ing sugars.	Gum.	Single polariza- tion	Reduc- ing sugars	Gum.
		per cent	per cent		per cent	per cent		per cent	per cent
0 6	9.0	0.22	0	8 5	0.12	0.10	6.5	2.67	0.30
2 4	8.7	0.14	0	8.8	0.20	0.04	8.7	0.23	0.09
3 6	8.5	0.20	0	8.7	0.15	0.04	8.6	0.14	0.01
6.0	8.1	0.13	0	8.4	0 06	0	8.2	0.07	0

At the greatest concentration of alkalinity there were present sufficient hydroxyl ions to stop entirely invertase activity which is paralleled by the absence of gum formation, thus indicating the causal relation previously referred to.

These experiments were repeated twice, the results confirming those set forth above, but it is superfluous to include these data at this point.

In the light of the foregoing experimentation we are able to arrive at a satisfactory explanation of the phenomenon of gum formation in sterile sugar solutions inoculated with certain microorganisms. Namely, the formation of gum from sucrose depends upon the inversion of the latter. The most favorable conditions are those where nascent dextrose and levulose are present in abundance when the reaction is optimum or practically neutral (in terms of hydrogen ion concentration). We have arrived

through somewhat different considerations at the same conclusion, in this respect, as that of Greig-Smith. There is, moreover, good reason to believe that nascent levulose is even a more favorable source for gum formation than nascent dextrose and that the reaction between levan and levulose (which is formed by hydrolysis) may be, to some extent, a reversible one. The basis for this hypothesis may be found in Table VII, where it is seen that there is an increase in polarization where nascent dextrose and levulose are being used as a source of gum formation, for the polarization of the controls is -2.0 , while that of spores and invertase is only -0.5 , indicating that more levulose than dextrose has been utilized. It follows that as a secondary source of supply an increase in sucrose involves an increase of nascent dextrose and levulose. Consequently it is justifiable to state that gum formation likewise depends on sucrose. Furthermore, we have evidence to show that, in the absence of sucrose or nascent dextrose and levulose, gum may be formed in small amounts from solutions containing c. p. dextrose and levulose present in equal quantities.

The above facts in no way conflict with the theoretical considerations governing the transformations which carbohydrates may undergo.

SUMMARY.

1. Levan is formed by levanase from mold spores most readily from nascent dextrose and levulose (obtained by the action of invertase on sucrose). There is evidence that nascent levulose is used to a greater extent than nascent dextrose in the formation of levan. In the absence of sucrose and nascent reducing sugars, slight gum formation was obtained with c. p. reducing sugars.

2. Levan is not formed directly from sucrose, but may be formed when the latter undergoes inversion.

3. Appreciable concentrations of acidity or alkalinity inhibit the activity of levanase. The optimum reaction appears to be about pH 7.0.

In conclusion, we wish to express our appreciation for the many helpful suggestions received from Assistant Director W. G. Taggart, Dr. F. W. Zerban, and Mr. W. L. Owen, and for the constructive criticism so generously offered by Dr. C. A. Browne.

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CONTRIBUTION TO THE CHEMISTRY OF PHOSPHO-MOLYBDIC ACIDS, PHOSPHOTUNGSTIC ACIDS, AND ALLIED SUBSTANCES.

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INTRODUCTION.

Phosphomolybdic and phosphotungstic acids have long been used in biological chemistry. The ordinary complex acids of commerce are common reagents for proteins, amino-acids, alkaloids, and other organic bases, while the specially prepared solutions of Folin and Denis have in recent years been used for the colorimetric determination of uric acid, adrenalin, phenol, sugar, etc. The chemistry of the complex acids is, however, little understood.

Having had frequent occasion to use the complex acids both as protein precipitants and as color reagents, the writer was led

to study certain phases of the chemistry of these compounds. With no intention of going into the field of the pure inorganic chemistry of these compounds, attention was confined at first to the color reaction of the Folin-Denis reagents with uric acid, and to the preparation of the ordinary phosphotungstic acid. As the investigation progressed, however, it was found desirable to extend the study so as to cover all the complex phospho-acids of molybdenum and tungsten.

The literature of the complex acids is voluminous and confusing. With the aid of the color reactions which lend themselves to qualitative differentiation as well as to quantitative estimation of the different complex acids, the writer was able to survey the field in a way that was scarcely possible before, and has arrived at a conclusion regarding the present status of our knowledge of the complex acids.

HISTORICAL.

Gmelin discovered that phosphoric acid formed a yellow precipitate in acid solution with ammonium molybdate. The precipitate contained so little phosphorus that he regarded it as unessential. Sonnenschein showed that phosphoric acid was an integral part of the precipitate and suggested its use for the quantitative determination of phosphoric acid. Debray prepared the free phosphomolybdic acid by digesting the yellow precipitate with aqua regia. The ratio of P_2O_5 to MoO_3 in the yellow precipitate and acid was according to Debray as 1:20, and according to Rammeisberg, 1:22. But the unanimous conclusion of Finkener, Pemberton, von der Pfordten, Gibbs (1881-82 *a*), and Hundeshagen that the compound contained 1 P_2O_5 to 24 MoO_3 is now generally accepted.

Scheibler in 1872 described two complex acids of tungsten. He boiled sodium acid tungstate ($Na_4H_3W_7O_{28} + 12 H_2O$) and half its weight of phosphoric acid, and obtained a crystalline compound of the composition $Na_4H_{11}P_2W_6O_{81} + 13 H_2O$. From this he prepared the barium compound which on decomposition (with sulfuric acid) gave a free acid $H_{15}PW_{11}O_{48} + 18 H_2O$. Using a slightly different procedure, he obtained another acid of the composition $H_{11}PW_{10}O_{38} + 8 H_2O$. He published no analyses, and he assigned the formulas to his compounds with reservation. There is no doubt that the work of Scheibler possesses only historical value.

Later Gibbs (1880-81 *a*) took up the study of the complex acids. He boiled 24 mols of $Na_2WO_4 + 2 H_2O$ with 2 mols of Na_2HPO_4 and acidified the mixture with nitric acid. The complex acid was precipitated with mercurous nitrate, and the mercurous phosphotungstate was decomposed with hydrochloric acid. The free acid thus obtained contained 1 P_2O_5 : 24 WO_3 . Sprenger, Kehrman and Freinkel (1891), and Brandhorst and

Kraut obtained the same compound by slightly different methods and all their analytical results showed that the ratio $P_2O_5:WO_3$ was as 1:24.

Besides the compounds containing 1 P_2O_5 to 24 MO_3 ($M = W$ or Mo) Gibbs (1880-81 *a, b*) reported others with the ratio $P_2O_5:MO_3$ as 1:22, 1:20, 1:18, and 1:16. These compounds were obtained only in the form of salts. The conditions under which they were formed were not well defined, and he believed that it was almost impossible to predict what complex would be formed under exactly similar conditions. He stated repeatedly that the compounds were "only to be distinguished by analysis," and he also admitted that some of his compounds could not be recrystallized and that consequently their absolute purity could not be guaranteed. Neither was the method of phosphate determination then available entirely adequate for his problem, and among other sources of error need be mentioned only the circumstance that he had to apply at times to his phosphoric acid determination a correction of 8 per cent, a magnitude as large as the difference between the P_2O_5 contents of the 1:24 and 1:22, or between the 1:20 and the 1:18 compounds. In view of all these facts, much of his work is of doubtful significance.

Pécharé also reported a number of phosphotungstic acids other than the 1:24 acid. He mixed theoretical quantities of *m*-tungstic acid and phosphoric acid, and claimed to have obtained acids with the ratio $P_2O_5:WO_3$ as 1:20, 1:16, and 1:12. He did not state his method of analysis, and, as far as can be judged from his published figures, duplicate analyses differing among themselves by 5 per cent or more, there is no convincing evidence that his compounds had the composition he assigned to them.

In 1887 Kehrman prepared a new phosphotungstic acid by boiling 1 mol of sodium tungstate with 4 mols of phosphoric acid. A set of peculiar circumstances led him to assign to his compound a formula with the ratio $P_2O_5:WO_3$ as 1:16. As a result of further research, he corrected his mistake a few years later (1892) and concluded that his compound really contained 1 P_2O_5 to 18 WO_3 . In collaboration with Böhm (1894 *a, b*) he succeeded in isolating the corresponding molybdenum compound from the mother liquor of the barium salt of the 1:24 acid by salting out with NH_4Cl . The ammonium salt crystallized out from the solution as orange-red prisms. The free acid was obtained by treating the potassium salt with theoretical quantity of sulfuric acid and precipitating the potassium sulfate with alcohol and ether. He also observed that the 1:24 phosphomolybdic acid was transformed into the 1:18 acid by free phosphoric acid on long standing, but no method for the preparation of the 1:18 compound was given. (Finkener had previously observed some sodium salt containing 1 P_2O_5 to MoO_3 , but, as he did not mention any detail, the discovery of the 1:18 acid is to be attributed to Kehrman.)

Kehrman and his collaborators observed that the 1:24 and 1:18 phosphotungstic acids were converted by carbonates into new complexes containing respectively 1 P_2O_5 to 22 WO_3 , and 1 P_2O_5 to 17 WO_3 . These complex salts corresponded to hypothetical acids of the composition $7 H_2O \cdot P_2O_5 \cdot 22 WO_3$ and $5 H_2O \cdot P_2O_5 \cdot 17 WO_3$, but when the salts were boiled with mineral acid the original 1:24 and 1:18 acids were regenerated

Kehrmann and Freinkel (1892) claimed to have prepared the acid containing 1 P_2O_5 to 21 WO_3 which was formed from the 1:22 salt simultaneously with the regeneration of the 1:24 acid. This finding the writer has not been able to confirm.

Compounds containing much smaller amounts of WO_3 or MoO_3 are also known. Thus the 1 P_2O_5 :15 MoO_3 compound was reported by Rammelsberg; the 1 P_2O_5 :5 MoO_3 compound by Rammelsberg, Zenker, Debray, Wernke, and Friedheim; the 1 P_2O_5 :4 MoO_3 and 1 P_2O_5 :2 MoO_3 by Friedheim; the 1 P_2O_5 :7 WO_3 by Gibbs (1880-81 b) and Kehrmann (1892). All these compounds, if they exist at all, are formed either from the higher acids by decomposition with insufficient alkali or from the molybdate and tungstate with insufficient acid. They have been prepared only in the form of salts, as they are converted by mineral acid into the 1:24 or the 1:18 acid.

The Present Status.

The complex phospho-compounds of molybdenum and tungsten fall into two well defined groups:

Group I.—This group includes the complexes containing 1 P_2O_5 to 24 MO_3 and 1 P_2O_5 to 18 MO_3 ($M = W$ or Mo). They can exist either as free acids or as salts. They are all colored, with the exception of the 1:24 tungsten compound. They are very sensitive to reduction, and precipitable with pyridine in dilute solutions. They are converted by alkali into compounds of Group II.

Group II.—This group includes a number of salts with different P_2O_5 : MO_3 ratios. They exist only in the form of salts, being converted by mineral acids into compounds of Group I. They are all white or colorless. They are not sensitive to reduction, and are not precipitable with pyridine in dilute solutions.

Compounds of Group II are not complex acids, and they have therefore received little attention in this research.

The properties and reactions which have been found useful in distinguishing the complex acids are shown in Table I.

The terms phosphotungstic acid and phosphomolybdic acid are used loosely to represent different compounds. The ordinary acids have been called phosphoduodecitungstic and phosphoduodecimolybdic acids, and the acids discovered by Kehrmann were named phospholuteotungstic and phospholuteomolybdic acids, indicating the yellow color of these compounds. It seems desirable to have a system of nomenclature of these complex

TABLE I.
Properties and Reactions of Complex Acids.

Reaction.	W		Mo	
	1:18	1:24	1:18	1:24
Color.	Lemon-yellow.	Colorless.	Bright yellow.	Orange.
NH ₄ salt.	Soluble.	Insoluble.	Soluble.	Insoluble.
With uric acid.	Blue coloration in alkaline solution.	Brown coloration in acid; blue in NaOH (but not in Na ₂ CO ₃) solution, fading rapidly.	Blue coloration in alkaline solution.	Blue coloration in alkaline or in acid solution with the complex in excess; violet with uric acid in excess.
With SO ₂ .	Blue coloration growing slowly in acid. Only a trace of color in alkaline solution.	Almost no reaction. Very faint violet coloration.	Blue coloration in alkaline or neutral solution.	Blue coloration in alkaline solution with the complex in excess; lavender-blue with SO ₂ in excess.
With ferrous salt.	Blue in alkaline. Almost none in acid solution.	Brown in acid, blue in alkaline solution, fading rapidly.	Blue in alkaline as well as in acid solution.	Blue in alkaline as well as in acid solution with the complex in excess; lavender-blue with the ferrous salt in excess.

compounds based on their composition rather than on their properties. The ratio $P_2O_5:MO_3$ or simply $P_2:M$ is better suited than the ratio $P:M$ for this purpose, because there are compounds containing 1 P_2O_5 to an odd number of MO_3 , in which case the ratio $P:M$ would have a fractional value. Greek numerals might be used, but it is by far simpler to insert an arabic numeral after the word "phospho," the numeral denoting the number of MO_3 to 1 P_2O_5 . Thus, the ordinary acid of molybdenum would be phospho-24-molybdic acid, Kehrman's tungstic acid would be phospho-18-tungstic acid, the salt obtained from this by the action of carbonate would be phospho-17-tungstate, etc.

Conditions of Formation of the Complex Acids.

The formation of the complex acids depends on four factors: (1) acidity or hydrogen ion concentration; (2) concentration of phosphoric acid; (3) concentration of tungstic acid or molybdic acid; and (4) temperature.

Acidity is the most important factor. A definite hydrogen ion concentration is apparently required to condense the simple tungstic acid or molybdic acid into a complex structure which then combines with phosphoric acid. A higher acidity is required to form $(MO_3)_{24}$ than $(MO_3)_{18}$, and for the molybdenum compound than for the corresponding tungsten compound. The concentration of tungstic or molybdic acid and that of phosphoric acid exert their effects in accordance with the mass action, but they are relatively unimportant. Boiling temperature is required to form the complex acids of the 1:18 series, but the 1:24 acids are formed even at ordinary temperatures.

The acidity of a mixture of sodium molybdate and phosphoric acid is not enough to form any complex acid (Group I). Whatever proportion of the two compounds is used, the solution contains only colorless complex molybdate (Group II), even after long boiling. Addition of hydrochloric acid to an equimolar mixture of Na_2MoO_4 and H_3PO_4 in an amount equivalent to the quantity of Na_2MoO_4 used, produces a mixture of the 1:18 and the 1:24 acid. The yield in the latter compound increases with increasing acidity.

The acidity of a mixture of 1 mol of $\text{Na}_2\text{WO}_4 \cdot 2 \text{H}_2\text{O}$ with 4 mols of H_3PO_4 suffices to transform all the tungstate into the 1:18 acid, but none of the 1:24 acid is formed. But if hydrochloric acid is added, the 1:24 acid will be formed almost to the exclusion of the 1:18 acid. The colorless complex tungstates are formed only when the solution is alkaline or weakly acid (in the presence of acetate).

Theoretically a mixture of tungstate or molybdate and phosphoric acid contains all the possible complexes, and the equilibrium can be displaced in one direction or another by suitable means. Thus the molybdenum compounds are very susceptible to transformation. A little ammonium chloride added to a solution of phospho-18-molybdic acid will cause the formation of the ordinary yellow precipitate in the course of time at room temperature, and rapidly at higher temperatures. The tungsten compounds are, however, more stable, and a solution of ammonium phospho-18-tungstate may be heated to 60–70°C. without danger of transformation.

Preparation of the Complex Acids.

The methods which have been employed for the preparation of complex acids of the 1:24 series consist in the double decomposition of the mercurous salt by hydrochloric acid, of the barium salt by sulfuric acid, or in the digestion of the ammonium salt with aqua regia. All these methods are at best very tedious. Drechsel suggested the use of ether for extracting the complex acid from an aqueous solution. This procedure simplified the preparation very materially. But the method, whether in Drechsel's original form or as modified by Winterstein, gives not a pure acid but a mixture. The ether extraction, as far as the writer is aware, has been used only for the preparation of the phospho-24-tungstic acid, although Drechsel stated that it could be used for the corresponding molybdenum compound. As a matter of fact, the great solubility in ether is a property common to all complex acids; and they can all be almost quantitatively extracted with ether from strongly acidified solutions.

Kehrmann obtained the phospho-18-tungstic acid by digesting the ammonium salt with aqua regia, and explicit directions were

given. The exact method for the corresponding molybdenum compound was not worked out.

From the study on the formation of the different complex acids and the recognition of their solubility in ether, simple methods have resulted for the preparation of pure complex acids.

Phospho-24-Molybdic Acid.

Dissolve 100 gm. of $\text{Na}_2\text{MoO}_4 \cdot 2 \text{H}_2\text{O}$ in 200 cc. of H_2O . Add 10 cc. of H_3PO_4 (85 per cent) and then 100 cc. of concentrated HCl . Transfer to a 1,000 cc. separatory funnel, add 150 cc. of ether, and shake. Cool under the tap. After standing for 10 to 15 minutes, three layers should be formed. Transfer the lowest layer, which contains nearly all the complex acid, to another funnel. Add 100 cc. of H_2O and shake. Then add 50 cc. of concentrated HCl and some more ether and shake again. Cool. The lowest layer is again transferred to another funnel and washed once more. Transfer the ethereal solution, which should be perfectly clear, to a beaker, add 25 cc. of H_2O and a few drops of concentrated HNO_3 ,¹ and evaporate on the water bath with occasional stirring until crystals begin to form on the surface. Allow to cool slowly. Yellow octahedra of the composition $3 \text{H}_2\text{O} \cdot \text{P}_2\text{O}_5 \cdot 24 \text{MoO}_3 + 59 \text{H}_2\text{O}$ are obtained.

Phospho-18-Molybdic Acid.

Dissolve 100 gm. of $\text{Na}_2\text{MoO}_4 + 2 \text{H}_2\text{O}$ in about 450 cc. of H_2O , add 15 cc. of 85 per cent H_3PO_4 and 80 cc. of concentrated HCl . Boil for 8 hours with return condenser. Cool. Stir in 100 gm. of powdered NH_4Cl . The crystalline precipitate, after settling, is filtered on a Buchner funnel, and sucked as dry as possible. Redissolve the precipitate in an equal weight of water. A part of the precipitate (NH_4 -phospho-24-molybdate) remains undissolved. Filter through hardened paper. To the perfectly clear solution add enough solid NH_4Cl to make a 20 per cent solution. If the solution is not stirred at all, the NH_4 -phospho-18-molybdate will replace the NH_4Cl *in situ* and larger crystals are formed in this way than when the solution is stirred. After standing 4 to 8 hours the crystals are transferred to a Buchner funnel and sucked as dry as possible. Redissolve in just enough water and evaporate at a low temperature ($40^\circ\text{C}.$) in a vacuum, until crystals begin to form. (The solution cannot be evaporated with the aid of a free flame or even on the steam bath because the ammonium salt is transformed into the insoluble yellow precipitate of the 1:24 series even at 60 – $70^\circ\text{C}.$) Allow to cool slowly to 5 – $6^\circ\text{C}.$ Transfer the crystals to a Buchner funnel, and suck as dry as possible. The suction is discon-

¹ If the solution turns brown or green in the course of evaporation more HNO_3 should be added.

tinued and the crystals are covered with a liberal quantity of dry ether. Stir to insure mixing, and, after a few minutes, suck as dry as possible. The crystals are then spread on a watch-glass and will be completely dry in an hour or so. The quick drying is necessary, as the product will be contaminated by some yellow precipitate formed from the mother liquor on slow drying. Orange crystals of the composition $3 (\text{NH}_4)_2\text{P}_2\text{O}_7 \cdot 18 \text{MoO}_3 \cdot 11 \text{H}_2\text{O}$ are obtained. They should give a perfectly clear solution in water.

The free phospho-18-molybdic acid can be prepared as follows:

Dissolve 50 gm. of the ammonium salt in 100 cc. of H_2O , add 60 cc. of concentrated HCl , and extract with ether in a separatory funnel. Cool. The lowest layer is transferred to another funnel. Add 100 cc. of H_2O and shake; then add 60 cc. of concentrated HCl and some more ether, and shake again. Repeat the washing once more. Transfer the ethereal solution to a tall beaker, add 40 cc. of H_2O , and blow off the ether by means of compressed air. Allow the solution to evaporate over H_2SO_4 . (Like the ammonium salt the free 1:18 acid is transformed into the 1:24 acid at high temperatures.) Orange prisms of the composition $3 (\text{NH}_4)_2\text{P}_2\text{O}_7 \cdot 18 \text{MoO}_3 \cdot 11 \text{H}_2\text{O}$ are obtained. The solution should give no precipitate with NH_4Cl .

Phospho-24-Tungstic Acid.

This acid is the chief ingredient of the commercial phospho-tungstic acid which is never pure. The Kahlbaum and Merck products contain about 10 per cent of the phospho-18-tungstic acid. To prepare pure phospho-24-tungstic acid proceed as follows:

Dissolve 100 gm. of $\text{Na}_2\text{WO}_4 \cdot 2 \text{H}_2\text{O}$ in about 100 cc. of H_2O with the aid of heat. Add 10 cc. of 85 per cent H_3PO_4 and then 80 cc. of concentrated HCl . Allow to cool. The crystalline precipitate which is gradually formed consists of sodium phospho-24-tungstate but is usually contaminated by traces of acid tungstates. After 4 hours or more, filter on a Buchner funnel and suck as dry as possible. Redissolve the precipitate in 120 cc. of H_2O , pour the solution into a liter separatory funnel, add about 70 cc. of ether, and then 40 cc. of concentrated HCl . Shake. After standing a few minutes there should be three layers of liquid. The lowest layer contains nearly all the complex acid. If there are only two layers, more ether should be added and the mixture shaken again. Transfer the lowest layer to another separatory funnel, add about 120 cc. of water and shake vigorously, then some more ether (30 cc.), and finally 40 cc. of concentrated HCl . Shake. After standing, the lowest layer, which should be perfectly clear, is transferred to a beaker. Add 20 cc. of H_2O and

evaporate on a steam bath until crystals begin to form on the surface. Colorless octahedra of the composition $3 \text{H}_2\text{O} \cdot \text{P}_2\text{O}_5 \cdot 24 \text{WO}_3 \cdot 59 \text{H}_2\text{O}$ are obtained.

Phospho-18-Tungstic Acids.

While preparing the ammonium salt of the acid in the uric acid reagent of Folin and Denis it was observed that the crystals first deposited had a different form from those which were deposited later. The two kinds of crystals differ also in other properties such as solubility, hardness, etc., but above all they differ in their chromogenic value. When equal weights (10 mg.) of them were dissolved in water, an excess of uric acid (5 mg.) was added, and the solution rendered alkaline with sodium carbonate (5 cc. of 20 per cent solution), the color (in 50 cc.) produced by the form first deposited was about 30 per cent stronger than that produced by the other form. Since analysis later showed that the stronger form contained a smaller per cent of tungsten it must be concluded that they were two different chemical individuals. As they both contain 1 P_2O_5 to 18 WO_3 , they are both phospho-18-tungstic acids. For convenience the stronger form will be designated as A, and the weaker form B. The B form has been identified with the leuteophosphotungstic acid of Kehrman, but the A form is hitherto unknown.² The exact relation between the two forms has not been determined, but as there is clearly the possibility of isomerism their properties, preparation, and analysis will be described in detail.

To 200 gm. of $\text{Na}_2\text{WO}_4 + 2 \text{H}_2\text{O}$ dissolved in a liter of water 280 gm. of 85 per cent phosphoric acid were added. The mixture was boiled for 8 hours under return condenser. Toward the end of the boiling the liquid was allowed to concentrate to a volume of about a liter. A few drops of

² It must be pointed out that Kehrman (1887) in his early study of the phosphotungstic acids had observed different crystalline forms of the yellow potassium salt which he prepared. He believed that there were three compounds represented by short prisms (lemon-yellow), monoclinic octahedra (pale yellow), and small needles (yellowish white), and these forms were designated by him as A, B, and C. The C form was deposited first, then followed the other two. However, he studied only the prismatic form A, of which he made some crystallographic measurements, but in his later work he did not refer to these findings.

bromine water were added to decolorize the solution, which turned to pure yellow. After cooling, about 200 gm. of powdered NH_4Cl were stirred in. The crystalline precipitate was filtered by suction, redissolved in water, and reprecipitated with solid NH_4Cl . This process was repeated twice. The precipitate was then dissolved in about 600 cc. of luke warm water (about $50^\circ\text{C}.$) and the solution³ allowed to stand in a warm room ($37^\circ\text{C}.$). After a few days the A crystals (2 to 3 mm.) were deposited in characteristic form, unmixed by any of the other kind. When the deposit ceased to grow, the mother liquor was decanted into another beaker. The A crystals were washed with ice-cold water and recrystallized five times from water.

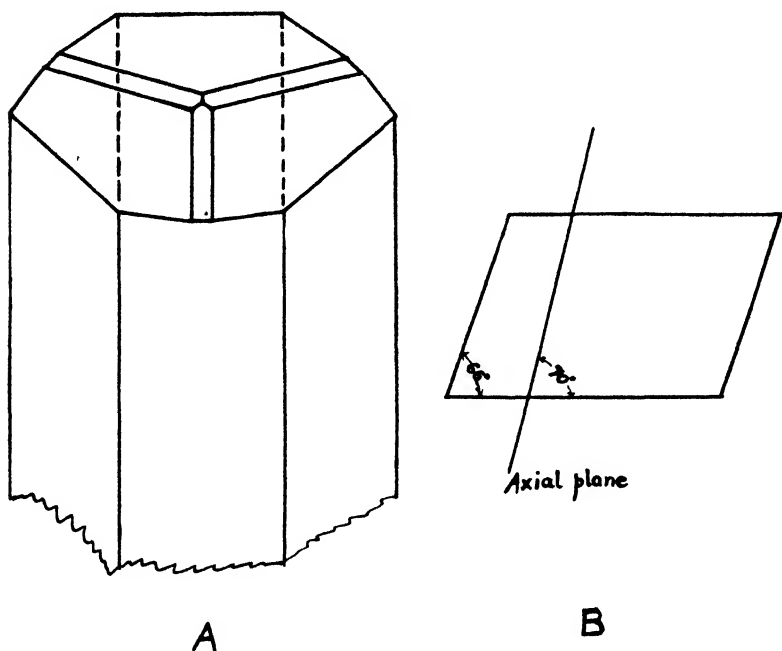


FIG. 1. A. Ammonium A-phospho-18-tungstate. Hexagonal prism truncated by two rhombohedra. The narrow faces are usually not developed.

B. Ammonium B-phospho-18-tungstate. Rhomboidal plate with truncated edges (not shown).

³ If the solution is somewhat colored, due to reduction of the complex acids by organic dusts, as is usually the case, the crystals of the A form will be much darker than those of the B form. Sometimes the former is almost black, whereas the latter is only faintly green. It is therefore possible to separate the two forms mechanically by means of forceps.

After another week or so the B crystals were formed. When the deposit apparently ceased to grow, it was separated from the mother liquor, dissolved in water, and allowed to recrystallize. The crystals were divided into three crops, the first and last were put aside for other use, while the middle crop was recrystallized four times. Large crystals (1 to 2 cm. long) were obtained.

The preparations were air-dried. Ground samples were used for analysis. Neither preparation gave test for chloride, showing that they were completely freed from the mother liquor which contained a large excess of phosphoric acid.

The yield in the A form was about 30 gm., representing about 20 per cent of the tungstate used.

The method of analysis used embodies certain improvements upon the older procedure. It is at once simple and accurate, and believed to be generally applicable to the analysis of complex phospho-compounds of tungsten and allied elements. The ammonium salt lends itself especially well to analysis, because of the ease with which the non-volatile constituents can be determined.

The method is as follows:

1. Determination of P_2O_5 .—

The P_2O_5 must be determined in the unignited sample, because some of it is always lost during ignition. 2.5 to 3 gm. of the substance are dissolved in about 25 cc. of warm H_2O , 25 to 30 cc. of a 10 per cent solution of sodium hydroxide are added, and the mixture is heated to boiling until the precipitate which is first formed has entirely redissolved. Continue the heating at a slightly reduced temperature for 20 minutes longer. By this process the complex acid is completely decomposed into phosphate and tungstate. Fusion with Na_2CO_3 as recommended in the literature⁶ was never found necessary. After cooling, add 5 to 6 gm. of ammonium chloride. When it has dissolved, add slowly 10 to 15 cc. of magnesia mixture (55 gm. of $MgCl_2 \cdot 6 H_2O$, 140 gm. of NH_4Cl , and 350

⁴ The method for P_2O_5 in phosphomolybdic acids is much simpler. The preliminary boiling with $NaOH$ is not necessary, since the complex molybdenum compounds are decomposed by excess of concentrated ammonia even at room temperature. Incidentally the contamination by silica from glass is practically eliminated and the double precipitation of the magnesium ammonium phosphate may be omitted.

⁶ See, for example, Scott, W. W., *Standard methods of chemical analysis*, New York, 3rd edition, 1918, 482.

cc. of concentrated NH_4OH to the liter), and then one-fourth volume of strong ammonia. After 4 hours the precipitate is filtered and washed with 1:4 ammonia. The precipitate is always contaminated by a considerable amount of silica dissolved from the beaker by the alkali and by a trace of tungstate. To remove these the precipitate is ignited, whereby the silica and tungstic acid are rendered insoluble. If the precipitate is merely redissolved in HCl without ignition, as is recommended in the literature,⁵ the impurities are only partly removed. Digest the ignited precipitate with 15 cc. of 2 N HCl for an hour at $80-90^\circ\text{C}$. with occasional stirring. Filter off the silica on a small filter paper ($1\frac{1}{2}$ inches diameter) and wash with ten 5 cc. portions of 0.5 N HCl . Add to the filtrate and washings 5 cc. of magnesia mixture and then very slowly 25 cc. of concentrated ammonia. The precipitate which is now pure magnesium ammonium phosphate is filtered after 4 hours, washed with 1:4 ammonia until free from chloride, ignited with the usual precautions, and weighed. As the amount of phosphate determined is only about 0.1 gm. and the quantity of reagents used is considerable, it is important to make a blank determination and make the correction, if any, accordingly.

2. *Determination of WO_3 .*—Many previous investigators determined the WO_3 in phosphotungstic acids by the difference between the combined oxide ($\text{WO}_3 + \text{P}_2\text{O}_5$) and the phosphoric anhydride. The combined oxide was determined by igniting the ammonium phosphotungstate or the mercurous phosphotungstate obtained by precipitating with mercurous nitrate. It was pointed out by Barber that the ignition residue always weighed less than the theoretical sum of P_2O_5 and WO_3 , using compounds of known composition, and he attributed this discrepancy to the partial reduction of WO_3 to some lower oxide. As a matter of fact experiments made by the writer showed that it was not due to this cause, although a trace of tungsten was almost always reduced, imparting a bluish color to the trioxide. When the ignition residue was dissolved in alkali and the P_2O_5 in it determined, the figure obtained was always lower than the true P_2O_5 content of the unignited substance, the difference amounting to 7 to 15 per cent of the P_2O_5 content. It was clear that some P_2O_5 was lost during ignition, and this probably accounted for the discrepancy which Barber had observed.

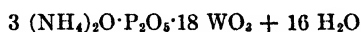
To determine WO_3 by difference, it is therefore necessary to determine the P_2O_5 in the ignited residue. Accordingly the determination of WO_3 is carried out as follows:

2.5 to 3 gm. of the substance are ignited in a platinum crucible placed inside a porcelain crucible which is heated to bright redness until the residue shows no appreciable loss of weight on successive weighings. The residue is then dissolved in 25 to 30 cc. of a 10 per cent solution of sodium hydroxide and the P_2O_5 in it determined as described above.

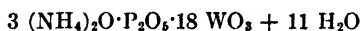
3. *Determination of Ammonia and Water.*—The ammonia is determined by distillation and titration in the usual manner, and calculated as $(NH_4)_2O$. The total water is determined by difference.

The results of the analyses representing two preparations each of A and B are shown in Table II and summarized in Table III.

A and B forms must therefore have respectively the formulas



and



Excepting the number of molecules of H_2O which may be in error by unity,⁶ the composition of the compounds as given is beyond any doubt.

The two forms thus differ only in the water content, and the anhydrous forms would have the same composition if the water is all "water of crystallization." There is then the possibility of isomerism and polymerism. But some of the water may be "water of constitution" and an anhydride relation may exist between the two forms.

The free acids of both forms are conveniently prepared from the corresponding ammonium salt by the ether extraction method, although they can also be obtained by digesting the salts with aqua regia.

A-Acid.—

Dissolve 10 gm. of salt in 25 cc. of water. Add 15 cc. of concentrated HCl and an excess (10 cc.) of ether and shake. Transfer the lowest layer to another separatory funnel, add 10 cc. of water, and shake; and then 6 cc. of concentrated HCl and some more ether and shake again. Transfer the ethereal solution to a beaker, add 5 cc. of water, and evaporate on the water bath until crystals begin to form on the surface. The crystallized acid has the composition $P_2O_5 \cdot 18 WO_3 \cdot 38 H_2O$.

⁶ This is true also for the formulas of other compounds given in this paper.

TABLE II.

Analyses of Ammonium Salts of Phospho-18-Tungstic Acids.

Preparation No.	Form A.			Form B.		
	Weight of sample.	Mg ₃ P ₂ O ₇	P ₂ O ₅	Weight of sample.	Mg ₃ P ₂ O ₇	P ₂ O ₅
	gm	gm.	per cent	gm.	gm.	per cent
I	3.0769	0.1431	2.963	3.1564	0.1516	3.067
	2.8336	0.1319	2.972	2.6205	0.1252	3.051
II	3.0538	0.1430	2.990	2.5099	0.1200	3.053
	2.5458	0.1184	2.970	2.7979	0.1339	3.055
Average.....			2.974			3.056

2. WO₃

	Form A.				Form B.			
	Weight of sample	Weight of residue	Mg ₃ P ₂ O ₇ from residue	WO ₃	Weight of sample.	Weight of residue	Mg ₃ P ₂ O ₇ from residue	WO ₃
	gm	gm	gm.	per cent	gm	gm.	gm	per cent
I	2.4787	2.2353	0.1003	87.58	2.6142	2.4094	0.1125	89.40
II	3.5249	3.1790	0.1420	87.61	3.7840	3.4869	0.1602	89.45
Average.....				87.595				89.425

3. (NH₄)₂O

	Form A			Form B		
	Weight of sample	0.1 N HCl neutralized	(NH ₄) ₂ O	Weight of sample.	0.1 N HCl neutralized.	(NH ₄) ₂ O
	gm	cc	per cent	gm	cc	per cent
I	1.1320	14.30	3.284	1.1258	14.60	3.370
II	1.2464	15.57	3.248	1.1659	15.12	3.370
Average.....			3.266			3.370

TABLE III

Composition of Ammonium Phospho-18-Tungstates.

		P ₂ O ₅	WO ₃	(NH ₄) ₂ O	H ₂ O (by difference).
Per cent	A	2.974	87.595	3.266	6.165
" "	B	3.055	89.425	3.370	4.150
Ratio	A	1	18.03	2.999	16.35
"	B	1	17.93	3.012	10.72

B-Acid.—

Dissolve 10 gm. of salt in 15 cc. of water. Add 10 cc. of concentrated HCl and extract with 10 cc. of ether. Then proceed as described for the A-acid. The crystallized B-acid has the composition $P_2O_5 \cdot 18 WO_3 \cdot 40 H_2O$.

The physical properties of the two forms of ammonium phospho-18-tungstate are shown in Table IV.

TABLE IV.
Properties of Ammonium Phospho-18-Tungstates.

	A	B
Solubility.	51* gm. in 100 gm. H_2O .	122* gm. in 100 gm. H_2O .
Strength.	Tough.	Brittle.
Color.	Lemon-yellow.	Pale yellow.
Deliquescence.	Does not lose water of crystallization easily.	Loses water of crystallization easily and crumbles into powder.
Crystallographic properties.†	Uniaxial. Simple hexagonal prism terminated by two rhombohedra, one of which, probably the unit form, is more strongly developed (Fig. 1). Habit: radial groups consisting of needles elongated in the direction of vertical axis. The second rhombohedron is usually not developed and the crystal then bears a superficial resemblance to a duodecahedron. Optical character, negative.	Biaxial. Probably triclinic. Habit: thin rhomboidal plates with truncated edges (Fig. 1). In one crystal studied the axial plane makes an angle of 70° with one edge and 4° with the other. With the plate lying flat the interference figure shows one axis well within the field. The angle E is estimated as 30° . Optical character, positive.

* Approximately.

† The writer is indebted to Professor C. H. Warren of the Massachusetts Institute of Technology for these observations.

Chemically the two forms are similar. They are both reducible by uric acid in alkaline solution, but the colors produced differ in quality as well as in intensity. For the same weight of WO_3 the A form gives about 30 per cent more color than the B form.

The color of the A form has a tint of green, that of B form, violet. The A form is more sensitive to reduction.

The comparison of the chromogenic values was made as follows:

To 1 cc. of 1 per cent solution of the ammonium salt in a 50 cc. volumetric flask were added, in the order given, 10 cc. of water, 5 cc. of 0.1 per cent uric acid solution (made by dissolving 0.1 gm. of uric acid and 0.1 gm. of lithium carbonate in 100 cc. of H_2O), 0.5 cc. of 5 per cent sodium cyanide, and finally 5 cc. of 20 per cent sodium carbonate solution. The cyanide was used to retard the fading, and it did not affect the relative color values. The color solution was diluted to volume and read in a 50 mm. Duboscq colorimeter. The ratio of the color intensities was

$$\frac{10 \text{ mg. NH}_4 - \text{A-salt}}{10 \text{ mg. NH}_4 - \text{B-salt}} = \frac{25.4}{20} = 1.27$$

or in terms of the anhydrous salts

$$A = 1.3 B$$

Two 1 cc. portions of the uric acid solution used in the preceding experiment were measured into two 100 cc. flasks. To one were added 10 cc. of 1 per cent solution of the A-salt, and to the other, the B-salt. 10 cc. of 20 per cent sodium carbonate solution were then added to each flask. The color solutions were diluted to volume and read. The ratio of the color intensities was

$$\frac{A}{B} = \frac{25.6}{20} = 1.28$$

TABLE V.

	P ₂ O ₅	WO ₃	(NH ₄) ₂ O	H ₂ O (by difference)
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
I	3.100	86.00	5.642	
II	3.095	85.98	5.687	
Average.....	3.098	85.99	5.665	5.247

When treated with sodium carbonate or hydroxide in the cold, the two forms of phospho-18-tungstic acid yield the same decomposition product. This consists of small glistening rectangular plates difficultly soluble in carbonate or hydroxide solution. The ammonium salt obtained by using ammonium carbonate is easily purified by recrystallization from water without undergoing any change. Analysis gave the following results (Table V).

The ratios $P_2O_5:WO_3:(NH_4)_2O:H_2O$ in the salt are as 1:16.99:4.993:13.36. It must therefore have the formula $5 (NH_4)_2O \cdot P_2O_5 \cdot 17 WO_3 + 13 H_2O$.

When the phospho-17-tungstate, whether obtained from the A or the B form, was boiled with hydrochloric acid, the phospho-18-tungstic acid regenerated was exclusively the B form. This was proved by identification of the ammonium salt of the regenerated acid, but it was also easily shown by a simple experiment as follows:

To 1 cc. of 1 per cent solution of the A-salt was added 1 cc. of $N Na_2CO_3$ solution. After 2 minutes (the decomposition was practically instantaneous) 2 cc. of $N HCl$ solution were added and the solution was heated in the boiling water bath for 30 minutes. A similar experiment on the B-salt was made side by side. 1 cc. of 1 per cent solution of ammonium phospho-17-tungstate and 1 cc. of 1 per cent solution of B-salt were also heated each with 1 cc. of $N HCl$ in the same bath. After cooling, the chromogenic values were compared as described above. The results follow:

10 mg. A-salt decomposed and regenerated...	= 9.7 mg. B-salt
10 " B-salt " " "	= 9.8 " "
10 " colorless salt regenerated.....	= 9.4 " "

Since 10 mg. of the A-salt are equivalent chromogenically to 12.7 mg. of B-salt, it is clear that by the process of decomposition and regeneration the A-salt has been transformed into the B-salt. Incidentally the experiment showed that regeneration was practically complete.

The exact relation between the two forms of phospho-18-tungstic acid, as well as the more general problem of the structure of the complex acids, stands in need of further study. This is, of course, a problem of inorganic rather than of biological chemistry.

Phosphomolybdictungstic Acids.

Mixed complex acids containing molybdenum and tungsten both of the 1:18 and of the 1:24 series have been prepared. The methods of their preparation are very similar to those of compounds containing only one metal. Their properties lie between those of the pure molybdenum and pure tungsten compounds and, to be sure, resemble more the pure compound of the

predominant element. Thus, the soluble ammonium salts of the mixed complex acid of the 1:18 series with high content of molybdenum are easily transformed into insoluble salts of the 1:24 series, while those with high tungsten content may be heated to 70°C. without danger of transformation. The sensitiveness to reduction of these compounds runs roughly parallel to their molybdenum content, if one uses as a measure of sensitiveness the intensity of the color produced from a given weight (20 mg.) of the ammonium salt, with an excess of sodium sulfite (10 cc. of 10 per cent solution).

The number of mixed complex acids must be very large, and here the possibility of isomerism is far greater than in the case of the pure molybdenum or tungsten compound. By using sodium tungstate and molybdate in different molecular ratios, the writer has obtained about twenty ammonium salts of the 1:18 series. When these salts are reduced with reagents which do not affect the pure tungsten compound, the amount of color produced is far more than can be accounted for by the amount of molybdenum in the form of pure molybdenum compound in them. Their reduction products also show a great variation in color, whereas the pure molybdenum and pure tungsten compounds give colors which are only slightly different from each other. The color changes from bluish green to violet as the proportion of tungsten is increased. The preparations showed no change by recrystallization from lukewarm water. They must therefore be either different chemical individuals or mixtures of two adjacent members of the series; for example, $3\text{H}_2\text{O} \cdot \text{P}_2\text{O}_5 \cdot 10\text{WO}_3 \cdot 8\text{MoO}_3$ and $3\text{H}_2\text{O} \cdot \text{P}_2\text{O}_5 \cdot 9\text{WO}_3 \cdot 9\text{MoO}_3$. These compounds would be not only isomorphous but all their properties would be so similar that their separation is practically impossible. A few compounds of the 1:24 series have also been obtained which likewise give different colors on reduction.

The mixed complex acids of the 1:24 series are of no particular interest, and it suffices to mention here that they were prepared from mixtures of tungstate and molybdate by essentially the same methods as described for pure acids of the 1:24 series.

The mixed complex acids of the 1:18 series, on the other hand, count among its members the chief component of the phenol reagent of Folin and Denis, and it is of practical impor-

tance to know the conditions of their formation. These have been found as follows:

1. In the absence of a strong acid (hydrochloric) the complex formed is one with high tungsten content (not very sensitive to reduction), no matter how much molybdate may be used. It appears that under this circumstance the MoO_3 is not sufficiently condensed to form a long chain; the excess MoO_3 remains in the form of colorless compounds of Group II.

2. A strong acid (hydrochloric) must be used in order to incorporate all the molybdic acid used in the complex. The greater the proportion of molybdenum used in the mixture, the larger is the amount of acid required.

3. In the presence of molybdic acid a considerable amount of strong acid may be used without the formation of the complexes of the 1:24 series. However, when too much strong acid is used the 1:24 complexes are formed with corresponding decrease in the yield of the 1:18 complexes.

Since the 1:18 complexes are the desired components of the phenol reagent, the condition should be so adjusted as to obtain the maximum yield of those products. The following method, which gives a solution identical with the "phenol reagent" of Folin and Denis, prepared according to the latest direction, is intended to illustrate the preparation of mixed complex acids of 1:18 series.

Dissolve 100 gm. of $\text{Na}_2\text{WO}_4 \cdot 2 \text{H}_2\text{O}$ and 25 gm. of $\text{Na}_2\text{MoO}_4 \cdot 2 \text{H}_2\text{O}$ in 700 cc. of H_2O . Add 50 cc. of 85 per cent H_3PO_4 and 100 cc. of concentrated HCl . Boil with return condenser for 8 hours. The resulting solution contains mixed acids of the 1:18 series with a bare trace of the acids of the 1:24 series, and may be diluted for use as a phenol reagent.

To prepare the pure 1:18 mixed acid proceed as follows:

Saturate the cooled solution with solid ammonium chloride. Filter the crystalline precipitate on a Buchner funnel. Redissolve in 150 cc. of warm water, and remove the insoluble yellow residue by filtration through hardened filter paper. Add to the clear filtrate an equal volume of concentrated HCl , extract with ether, and proceed as described under the preparation of the phospho-18-molybdic acid. The mixed acids of the 1:18 series suffer transformation at high temperatures to the 1:24 acid, and the solution should be evaporated at room temperature, preferably over H_2SO_4 .

If only the ammonium salt is desired, it may be salted out with NH_4Cl from the clear solution and recrystallized from warm water. The free acid should give no precipitate (amorphous) with ammonium chloride, and the ammonium salt should give a perfectly clear solution.

Analysis of the ammonium salt, which was chloride-free, gave the following results (Table VI).

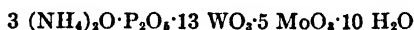
TABLE VI.

	P_2O_5	WO_3	MoO_3	$(\text{NH}_4)_2\text{O}$	H_2O (by difference).
Per cent.....	3.327	73.57	15.10	3.690	4.313
Ratio.....	1	13.55	4.48	3.060	10.24

The P_2O_5 , the combined oxides, and the $(\text{NH}_4)_2\text{O}$ were determined as described under the phospho-18-tungstic acids; the molybdenum was separated from the tungsten by the tartaric acid method of Rose, and determined directly. It will be noted that the ratio

$$\frac{\text{WO}_3 + \text{MoO}_3}{\text{P}_2\text{O}_5} = 18.03$$

showing that the compounds belong to the 1:18 series. The sample analyzed was clearly not a chemical individual, but a mixture of



and



It is to be noted also that the ratio $\text{MoO}_3 : \text{WO}_3$ in the complex is about the same as the ratio of the molybdate to the tungstate used in the preparation, and it seems that individual mixed acids can be obtained by starting with molybdate and tungstate in ratios of integers which give a sum of 18.

Reduction of the Complex Acids.

The phosphotungstic and phosphomolybdic acids are very sensitive to reduction, remarkably so in comparison with the corresponding simple acids. The complex acids are, indeed, akin to chromic acid in their power of oxidation and in their

color, and in these respects they, rather than the simple acids, represent molybdenum and tungsten in their periodic relation with chromium.

The complex acids yield on moderate reduction highly colored compounds which resemble the corresponding unreduced compounds in all respects except that of color. Thus, the reduced phospho-24-molybdic and phospho-24-tungstic acids form difficultly soluble ammonium salts. The salts of the reduced phospho-18-molybdic and phospho-18-tungstic acids are soluble, but they can be salted out with ammonium chloride. All are precipitable with pyridine in acid solution and all are extractable with ether. The methods described for the isolation and purification of the unreduced compounds are also applicable to the reduced compounds.

The complex acids arranged in the order of increasing sensitiveness to reduction are as follows:

1. Phospho-24-tungstic acid.-
2. B-Phospho-18-tungstic acid.
3. A-Phospho-18-tungstic acid.
4. Phospho-24-molybdic acid.
5. Phospho-18-molybdic acid.

The last two acids react with a variety of mild reducing agents in acid as well as in alkaline solution, while the first three are reduced only when the solution is rendered alkaline. The sensitiveness to reduction runs parallel with the color of the compound, and this parallelism holds also for the mixed complex acids.

The salient feature of the reduction of the complex acids is that the sensitivity is localized in one or two atoms of the metal in the 1:18 series, and probably the same number in the 1:24 series. This view finds support in the fact that complex salts of the 1:17 and 1:22 series formed respectively from the 1:18 and 1:24 acids with the loss of one and two atoms of the metal are totally inert.

Mild reducing agents (ferrous salt, sulfite, uric acid, etc.) affect only the sensitive atoms, and the resulting products are still complex acids. But if the reduction is carried further, for example, by means of an excess of zinc and hydrochloric acid,

the complex structure is disintegrated and all the atoms of the metal originally in the complex can be reduced just as those in the simple acids would be under the same circumstance. The disintegration of the complex is shown by the fact that pyridine no longer produces a precipitate and that after reoxidation the simple tungstic acid or molybdic acid can be seen suspended.

The reduced complex acids are readily restored to the original by oxidation, for example with bromine water. This shows that none of the atoms of the metal is detached from the complex. Consequently the exact composition of the reduced compounds has to be inferred from their oxidation-reduction equivalent, because the difference is too small to be determined with certainty by direct analysis. The oxidation-reduction equivalent was determined by titration of the reduced compound with potassium permanganate and by comparison of the maximum color produced by a given amount of the complex (in the presence of an excess of reducing agent) with that produced by a given amount of the reducing agent (in the presence of an excess of the complex acid). This latter method is applicable, of course, only when the colors produced are the same and are not interfered with by the products of the reaction. The data on the oxidation-reduction equivalents have been obtained mainly from the study of the molybdenum compound.

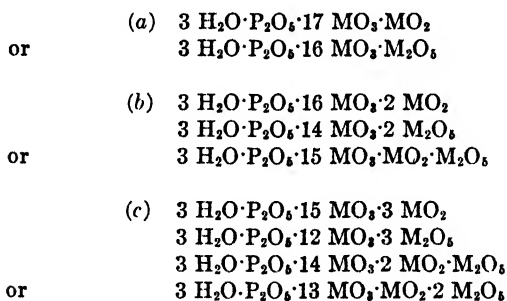
Just as molybdenum and tungsten trioxides yield on reduction a number of lower oxides, so also do the complex acids give rise to new complexes containing different lower oxides. The exact compounds formed depend on the nature and amount of the reducing agent, and on whether the solution is acid or alkaline. Thus uric acid reduces in acid solution the phospho-24-tungstic acid, forming a brown-colored complex, but if the solution is rendered alkaline by sodium hydroxide the compound formed is blue in color. The phospho-24-molybdic acid gives a lavender-blue compound with excess of the reducing agent and a greenish blue compound when the complex acid is in excess. It is of course a matter of common observation that different polyphenols and other substances which react with the "uric acid reagent" and the "phenol reagent" usually produce colors of different shade which cannot be wholly accounted for by the color of the oxidation products of phenols.

No attempt was made in this research to prepare all the possible complexes containing lower oxides of tungsten and molybdenum. But a few of them have been obtained in pure state to indicate the possibility of others.

Phospho-18-molybdic acid is reduced with the loss of 1, 2, or 3 atoms of oxygen. The ammonium salts corresponding to these stages have been obtained pure. The tungsten compounds undergo reoxidation rapidly when removed from the reducing medium. They could doubtless be prepared pure in a non-oxidizing atmosphere, but this experiment has not been undertaken. From their analogy with the molybdenum compounds, however, their composition may be inferred.

Complex compounds formed from the 1:24 acid by the loss of only 2 and 4 atoms of oxygen have been obtained, but the possibility of others is of course not excluded. Here again, the reduced phospho-24-tungstic acids show such a tendency to be reoxidized that one has to be content with drawing conclusions by analogy with the molybdenum compound.

The formulas of the reduced complex acids of the 1:18 series, as inferred from their oxidation-reduction equivalents, may be represented as follows:



It should be noted that it is not a matter of indifference whether, for instance, the compound (a) has the first or the second formula. The first contains one tetravalent atom, and the second, two pentavalent atoms of the metal. It is quite conceivable that the molybdenum or tungsten atoms of different valency are responsible for different shades of color of the reduced complex acids as they are in the simple lower oxides. The gradual increase

in the intensity of the blue color obtained in uric acid determinations may be explained by the conversion of MO_2MO_3 into M_2O_5 in the complex or *vice versa*. It is easy to understand why different shades of color are produced with the same complex acid under different conditions of reduction, especially in the case of the phenol reagent, for here the number of possible structures corresponding to the loss of the same number of oxygen atoms is greatly increased.

Reduction Experiments.

Reduction of Phospho-18-Tungstic Acids by Uric Acid.—Two color solutions representing the maximum color obtainable respectively from 10 mg. of $\text{NH}_4\text{-A-phospho-18-tungstate}$ and 0.3 mg. of uric acid were prepared as follows: (1) 10 cc. of 1 per cent uric acid solution (made by dissolving 1 gm. of uric acid and 1 gm. of Li_2CO_3 in 100 cc. of H_2O) + 2 cc. of 10 per cent Na_2SO_3 + 1 cc. of 5 per cent NaCN + 1 cc. of 1 per cent $\text{NH}_4\text{-A-phospho-18-tungstate}$ + 10 cc. of 20 per cent Na_2CO_3 , and water to a volume of 50 cc. (2) 1 cc. of 0.03 per cent uric acid solution + 2 cc. of 10 per cent Na_2SO_3 + 1 cc. of 5 per cent NaCN + 10 cc. of 20 per cent Na_2CO_3 + 10 cc. of 1 per cent $\text{NH}_4\text{-A-phospho-18-tungstate}$, and water to a volume of 50 cc.

The Na_2SO_3 and NaCN together retarded the fading, but did not intensify the color as NaCN alone would, and in this case unequally. The ratio of the color intensities was

$$\frac{10 \text{ mg. A}}{0.3 \text{ mg. uric acid}} = \frac{22.7}{20}$$

or

$$10 \text{ mg. A} \approx 0.34 \text{ mg. uric acid}$$

A similar experiment with $\text{NH}_4\text{-B-phospho-18-tungstate}$ gave

$$10 \text{ mg. B} \approx 0.32 \text{ mg. uric acid}$$

Since the A form contains 87.6 per cent WO_3 , and the B form 89.4 per cent WO_3 , it follows that $18.6 \text{ WO}_3 \approx 1$ uric acid for the A form and $20.2 \text{ WO}_3 \approx 1$ uric acid for the B form. Considering the inequality of conditions of the color solutions, it may be concluded that $18 \text{ WO}_3 \approx 1$ uric acid or $3 \text{ H}_2\text{O} \cdot \text{P}_2\text{O}_5 \cdot 18 \text{ WO}_3 \approx 1$ uric acid for either form of the complex acid.

Reduction of Phospho-18-Tungstic Acids in Alkaline Solution by Ferrous Sulfate.—1 cc. of freshly prepared 0.005 N solution of ferrous ammonium sulfate in 0.2 N H_2SO_4 was transferred by means of an Ostwald pipette to a 50 cc. volumetric flask. 2 cc. of 5 per cent solution of B-phospho-18-tungstic acid were added, followed by 10 cc. of 20 per cent sodium carbonate solution. 1 cc. of 1 per cent solution of ammonium B-phospho-18-

tungstate was placed in another 50 cc. flask, 5 cc. of the ferrous sulfate solution were added, and diluted with 20 cc. of water, followed immediately by 10 cc. of carbonate solution. Both flasks were then diluted to the mark and mixed. The first solution was not diluted with water before the addition of the carbonate, because the dilute ferrous sulfate solution could not be diluted with water without undergoing considerable oxidation. The dilution was necessary in the second solution to avoid precipitation of the colored compound together with the ferric hydroxide.

The second solution was centrifuged to remove the ferric hydroxide. (Filtration could not be used, because filter paper would absorb some of the blue color.) The solutions were read in a Duboseq colorimeter. The ratio of the color intensities was

$$\frac{\text{1st solution}}{\text{2nd solution}} = \frac{23}{20}$$

Now since preliminary experiments had shown that the colors obtained in the first and second flasks were the maximum colors obtainable respectively from 1 cc. of 0.005 N ferrous salt, and 1 cc. of 1 per cent complex salt, and since the latter contained 89.4 per cent of WO_3 , it follows that 1 cc. of 0.005 N ferrous salt $\approx \frac{23}{20} \times 0.00894 \approx 0.0103$ gm. WO_3 . Whence $8.85 \text{ WO}_3 \approx \text{Fe}$.

A similar experiment with the A form gave

$$\frac{1 \text{ cc. of 0.005 ferrous salt}}{1 \text{ cc. of 1 per cent complex salt}} = \frac{23.6}{20}$$

Since the ammonium salt of the A-acid contained 87.6 per cent of WO_3 , it followed that 1 cc. of 0.005 N ferrous salt $\approx \frac{23.6}{20} \times 0.00876 \approx 0.0104$ gm. of WO_3 . Whence $8.90 \text{ WO}_3 \approx \text{Fe}$.

In either case the ratio $\text{WO}_3:\text{Fe}$ was close enough to 9:1 to justify the conclusion that $3 \text{ H}_2\text{O} \cdot \text{P}_2\text{O}_5 \cdot 18 \text{ WO}_3$ loses 1 atom of oxygen when reduced by ferrous salt in alkaline solution.⁷

Comparison of the Colors Obtained by Reduction with Uric Acid and with Ferrous Salt.—1 cc. of freshly prepared 0.01 N solution of ferrous ammonium sulfate in 0.2 N H_2SO_4 was placed in a 100 cc. volumetric flask. In another flask was placed 1 cc. of 0.1 per cent solution (= 1 mg.) of uric acid dissolved with the aid of lithium carbonate. To each flask were then added 2

⁷ Sometimes the ferric hydroxide remained in colloidal solution, in which case the experiment was of course discarded. At other times the two color solutions did not match well and slightly different readings may be obtained by different observers. This does not, however, alter the conclusion already reached.

cc. of a 10 per cent solution of B-phospho-18-tungstic acid, followed by 20 cc. of 20 per cent sodium carbonate solution. The solutions were diluted to the mark, mixed, and read in a Duboscq colorimeter. The ratio of the color intensities was

$$\frac{1 \text{ mg. uric acid}}{1 \text{ cc. 0.01 N ferrous salt}} = \frac{23.8}{20} = 1.19$$

The experiment was repeated using the A form with the same result. If 1 molecule of uric acid was oxidized by 1 atom of oxygen, the 0.1 per cent solution was exactly 0.0119 N. It is therefore to be concluded that 1 molecule of uric acid reacts with 1 molecule of $3 \text{ H}_2\text{O} \cdot \text{P}_2\text{O}_5 \cdot 18 \text{ WO}_3$, confirming the results already obtained in the two previous experiments.

When the methods employed in the above experiments were applied to the corresponding molybdenum compound, the results obtained were not rational, probably because different reduction products were formed. This was to be expected from the much greater susceptibility to reduction of the molybdenum as compared with the tungsten compound. But another possible reason was that the molybdenum compound was also more readily decomposed by alkali, so that a part of it may be decomposed instead of being reduced.

Preparation of Ammonium Salts of Reduced Complex Acids: $3 (\text{NH}_4)_2\text{O} \cdot \text{P}_2\text{O}_5 \cdot 17 \text{ MoO}_3 \cdot \text{MO}_3 + \text{H}_2\text{O}$.—The phospho-18-molybdic acid is reduced only with the loss of 1 atom of oxygen by ferrous salt in acid solution. The reduction is an incomplete reaction and a large excess of the reducing agent must be used to prepare the reduced compound.

10 gm. of ammonium phospho-18-molybdate and 25 gm. of ferrous sulfate were dissolved together in 60 cc. of 10 per cent sulfuric acid. When all the solid substances had dissolved, 12 gm. of ammonium chloride were stirred in. Immediately a black crystalline precipitate was formed which after standing 10 minutes was filtered on a small Buchner funnel and washed with 20 per cent ammonium chloride solution until free from iron. The precipitate was redissolved in 50 cc. of warm water and evaporated at 60°C . until crystals began to form on the surface and allowed to cool slowly. Black crystals. It lost 12.50 per cent of its weight on gentle ignition. By calculation (on the basis of 1 P_2O_5 to 18 MoO_3 in the residue) 1 gm. of the substance ≈ 0.8295 gm. of MoO_3 . 14.30 cc. of 0.01 N permanganate were required to titrate 0.2206 gm. of the substance. Whence $18 \text{ MO} \approx \text{O}$.

The corresponding tungsten compound could be prepared by reduction with slight excess of Zn and hydrochloric acid in the cold, but, as already mentioned, it could not be easily purified.

3 $(\text{NH}_4)_2\text{O} \cdot \text{P}_2\text{O}_5 \cdot 16 \text{MoO}_3 \cdot 2 \text{MoO}_2 + \text{H}_2\text{O}$.—10 gm. of the orange molybdenum salt were dissolved in 50 cc. of H_2O , and 5 cc. of 40 per cent HI and 5 gm. of NaHSO_3 were added. The mixture was allowed to stand 24 hours. 10 gm. of solid NH_4Cl were stirred in. After a few minutes the crystalline precipitate was filtered on a Buchner funnel, washed with 20 per cent NH_4Cl solution until free from sulfate, and finally once with ice-cold 5 per cent NH_4Cl solution, and sucked as dry as possible. The product was recrystallized from warm water. Black crystals. It lost 21.45 per cent of its weight on ignition. By calculation 1 gm. of the substance \approx 0.7447 gm. of MoO_3 . 0.2595 gm. of the substance required 14.46 cc. of 0.02 N KMnO_4 to discharge the blue color. Whence 18 Mo \approx 20.

3 $(\text{NH}_4)_2\text{O} \cdot \text{P}_2\text{O}_5 \cdot 16 \text{MoO}_3 \cdot 2 \text{MoO}_2 + \text{H}_2\text{O}$.—10 gm. of the orange salt were dissolved in 50 cc. of H_2O , 5 cc. of 40 per cent HI were added, and a current of H_2S was passed into the solution until the latter was saturated. After 24 hours the solution was filtered to remove the sulfur. The filtrate was treated with 10 gm. of solid ammonium chloride. The crystalline precipitate was filtered and washed with 20 per cent NH_4Cl solution until free from iodide. The product was recrystallized once from warm water. Black crystals, with violet reflex. The preparation lost 18.65 per cent of its weight on ignition. By calculation 1 gm. of the substance \approx 0.7713 gm. of MoO_3 . 22.90 cc. of 0.02 N permanganate were required to titrate 0.2615 gm. of the substance. Whence 18 $\text{MoO}_3 \approx$ 30.

3 $(\text{NH}_4)_2\text{O} \cdot \text{P}_2\text{O}_5 \cdot 22 \text{MoO}_3 \cdot 2 \text{MoO}_2 + \text{H}_2\text{O}$.—10 gm. of phospho-24-molybdiic acid were dissolved in 50 cc. of H_2O . 5 cc. of 40 per cent HI and 5 gm. of NaHSO_3 were added. When all the sulfite had dissolved, 10 gm. of NH_4Cl were stirred in. The amorphous precipitate was filtered, washed with NH_4Cl until free from sulfate, and finally once with water. Blue powder. It lost 11.07 per cent of its weight on ignition. By calculation 1 gm. of the substance was equivalent to 0.8541 gm. of MoO_3 . 0.3268 gm. of the substance suspended in water required 15.05 cc. of 0.02 N KMnO_4 for the titration. Whence 24 $\text{MoO}_3 \approx$ 20.

3 $(\text{NH}_4)_2\text{O} \cdot \text{P}_2\text{O}_5 \cdot 20 \text{MoO}_3 \cdot 4 \text{MoO}_2 + \text{H}_2\text{O}$.—If in the above experiment the reacting mixture was allowed to stand 24 hours, the reduction would proceed further. The resulting product was quite soluble and was separated from the solution by saturation with NH_4Cl . A deposit of black precipitate was formed on standing. It was filtered, washed with 20 per cent NH_4Cl solution until free from sulfate, and finally once with water. The preparation lost 15.55 per cent of its weight on ignition. By calculation 1 gm. of the substance was equivalent to 0.8110 gm. of MoO_3 . 0.2668 gm. required 24.85 cc. of 0.02 N KMnO_4 for titration. Whence 24 $\text{MoO}_2 \approx$ 40.

Application of Complex Acids in Analytical Chemistry.

Phosphomolybdic and phosphotungstic acids have been used largely in organic analysis. The readiness with which the complex acids undergo reduction and the intensity of the color of the

resulting products should render them widely useful also in the analysis of inorganic compounds. The suggestions which follow are intended to illustrate the many uses to which the complex acids may be put. The mixed complex acids of the 1:18 series prepared as described above combine the stability of the pure tungsten compound and the sensitiveness of the pure molybdenum compound, and for use as color reagents they cannot be surpassed.

The complex acid solution should of course give no color when rendered alkaline. Sometimes the complex acid solution assumes a greenish tint due to some reduction by organic dust. This is of no practical consequence, but it can be removed by a few drops of bromine water. The excess of the bromine should of course be boiled off.

1. Detection of Copper.—Cuprous copper reduces the complex acid. The color of the reduction product is so intense that one part of Cu in 5,000,000 parts of water gives an unmistakable test. It is at least 50 times as sensitive as the ferrocyanide reaction. To apply the test to cupric copper proceed as follows:

To the copper solution add a few drops of 5 per cent potassium cyanide solution, acidify with HCl, followed by a few drops of the solution of the complex acid ("phenol reagent"). Mix. If more than a trace of copper is present the solution will become blue at once. But if only a trace of copper is present, the blue color will be obscured by the yellow color of the complex acid. Render the solution alkaline with saturated sodium carbonate solution, whereupon the unreduced yellow complex acid is transformed into a colorless salt. If copper is present the solution will now be blue.

The complex acids react also with ferrous salts, hydrogen sulfide, hydrogen iodide, sulfur dioxide, stannous chloride, etc., and its usefulness for the detection as well as for the colorimetric determination of these substances is apparent.

*2. Detection of Phosphoric Acid.*⁸—Hydrogen iodide reduces phosphomolybdic acids but not simple molybdic acid in the cold. Since the phospho-24-molybdic acid is formed from phosphoric acid and molybdic acid even in the cold, the presence of phosphoric acid can be tested with the aid of hydrogen iodide. The test may be made as follows:

⁸ Arsenomolybdic acids probably react like phosphomolybdic acids.

To the solution to be tested, add 1 to 2 cc. of 2 per cent pure ammonium molybdate solution, then 2 to 3 cc. of 10 per cent potassium iodide solution, 1 cc. of 10 per cent NaHSO_3 solution, and finally 1 to 2 cc. of concentrated HCl . Mix the solution and allow to stand. The color develops slowly when the amount of phosphoric acid present is small, but the solution will assume a greenish tint after 10 or 20 minutes even when only a trace of phosphoric acid is present. The bisulfite destroys the iodine liberated and hastens the reaction, but it imparts to the solution a yellow color and tends to obscure the blue color of the reduced phospho-24-molybdic acid. Render the solution alkaline with saturated sodium carbonate solution. The yellow color will now disappear and a pure blue color will be obtained. One part of phosphorus in 1,000,000 parts of water gives unmistakable test. It is well to carry a blank to insure that the reagents used are free from phosphoric acid.

3. Colorimetric Determination of Phosphoric Acid.—The qualitative reaction for phosphoric acid can be made the basis of a colorimetric method for the determination of that substance. The writer expects to apply the method to biological fluids and to describe the details elsewhere. The provisional procedure may be given as follows:

To the unknown solution containing 0.1 to 0.2 mg. of P in a volume of about 5 cc. add 5 cc. of each of the following solutions: 10 per cent sodium bisulfite, 10 per cent potassium iodide, 2 per cent ammonium molybdate, and 1:1 HCl . Add the same solutions to 5 cc. of standard phosphate solution containing 0.15 mg. of P. Mix. Cover the flasks (graduated at 50 cc.) with watch-glasses and allow to stand for 2 hours. Then add to each flask 10 cc. of 20 per cent sodium carbonate solution, shake to hasten the escape of CO_2 , dilute volume, mix, and compare the color values in a colorimeter (Duboscq). The color developed at the end of 2 hours is not the maximum, but it is sharply proportionate to the amount of phosphoric acid within the range from 0.1 to 0.22 mg. of P.

4. Indicator in Oxidation-Reduction Titrations.—An inside indicator for oxidation-reduction titrations is a long felt want in analytical chemistry. The advantages of the dichromate solution are offset by the inconvenience of the outside indicator. If to a ferrous salt solution a few drops of the mixed complex acid solution are added, the solution will be colored blue until all the ferrous iron is oxidized. Unfortunately the green color of the chromium salt tends to obscure the end-point, and satisfactory results can be obtained only when the amount of chromium involved is small (about 30 cc. of 0.02 N bichromate solution),

and then it is also necessary to have a blank by the side for comparison.

If no colored compound is produced in the oxidation-reduction reaction, the end-point is then very sharp. This is the case when a ferrous solution is titrated with a solution of hydrogen peroxide. The following experiment may be cited.

20 cc. of 0.05 N ferrous ammonium sulfate (in 10 per cent H_2SO_4) solution were measured into an Erlenmeyer flask, and three drops of the complex acid solution were added. An approximately N/15 solution of hydrogen peroxide was then run into the iron solution until all the blue had disappeared and a pure yellow color (due to complex acid) was obtained. 29.98 cc. of H_2O_2 were used. 30 cc. of the same solution required exactly 20 cc. of standard 0.05 N KMnO_4 solution for the titration. In this experiment a solution of ferrous salt previously titrated with a slight excess of H_2O_2 was placed by the side for comparison when the end-point was approached.

Hydrogen peroxide does not of course keep well enough to be depended upon for constant use, unless it is standardized with KMnO_4 whenever used. The writer offers the suggestion only to indicate the possibility of this novel use of the complex acid.

SUMMARY.

1. There are two series of complex phospho-acids of molybdenum and tungsten. In one series the ratio $\text{P}_2\text{O}_5 : \text{MO}_3$ is as 1 : 18; in the other, as 1 : 24. The "uric acid reagent" and "phenol reagent" of Folin and Denis contain acids of the former series.

2. Distinguishing reactions for the different complex acids are given.

3. Conditions of the formation of complex acids have been studied, and simple methods for the preparation of all the complex acids have been worked out.

4. Two phospho-18-tungstic acids, possibly isomeric forms, have been prepared.

5. A large number of complex acids containing both molybdenum and tungsten are shown to exist, and the method of their preparation is illustrated by an example.

6. Complex acids give on moderate reduction a number of new complex acids containing lower oxides of molybdenum and tungsten. The possibility of isomerism in these compounds is discussed.

7. New applications of the complex acids in analytical chemistry are illustrated by their use for the detection of minute quantities of copper and of phosphoric acid, for the colorimetric determination of phosphoric acid, and by their use as inside indicator for oxidation-reduction titrations.

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REACTION OF MILK IN RELATION TO THE PRESENCE OF BLOOD CELLS AND OF SPECIFIC BACTERIAL INFECTIONS OF THE UDDER.

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INTRODUCTION.

In a previous paper (Van Slyke and Baker, 1919) it has been shown that certain relations exist between the reaction of apparently normal milk and its chemical composition; and brief reference is made to the relation between the reaction of milk and the presence of leucocytes and streptococci. In conclusion it is stated that the conditions are such that they support the idea that the low hydrogen ion concentration occasionally found in freshly drawn milk is due to the presence of blood serum in the milk. Because of the importance of this suggestion in explaining bacteriological and physiological problems, the biological data that have a bearing on this theory are discussed in the present paper.

It is well known that under abnormal conditions not only blood serum, but blood itself may enter without change into milk as secreted. In some cases the blood enters because of hemorrhages due to injury or natural rupture of blood vessels; but in other cases the blood enters because of pathological conditions that are caused by specific bacterial infections. The commonest of the pathogenic organisms that cause the breaking down of the glandular tissue are the pathogenic streptococci, and this type of infection is the only one that has been studied during the present investigation. It should not be forgotten, however, that pathogenic staphylococci, organisms of the colon group, *Bacillus pyogenes*, the organism of bovine tuberculosis, and species of *Actinomyces* have all been described as causing similar infections (Wall,

1918). Recently attention has been called to infections of the udder with *Bacterium abortus* by Schroeder and Cotton (1911).

It has been abundantly established by a comparison of the composition of blood serum and of normal milk that the nutrient materials of the latter are quite different from those of the former. Normal milk solids are the product of the secretory activity of the glandular epithelium. The cells in this epithelium secure their raw materials from the blood serum, or more directly from the lymph, and transform them into the fats, casein, lactose, and other solids of the milk. Few substances other than water and some of the mineral salts pass unchanged into milk during normal secretion.

The situation in regard to the formed elements in the blood such as the red and white corpuscles differs from that just discussed. The red cells do not pass into the milk under normal conditions, while leucocytes have been shown to be so universally present that they must be regarded as a normal constituent of market milk (Breed, 1914). The numbers of these leucocytes are highly variable, and in milk of normal type they occasionally occur in such small numbers as to be practically absent. Even in the majority of samples of market milk, the number of these leucocytes is not large as compared with the number present in the blood; *i.e.* less than 500 per cm. for the majority of milk samples as compared with a normal of 7,500 per cm. for blood.

Accompanying these leucocytes in milk, there are smaller numbers of fat-laden epithelial cells (so called colostrual corpuscles) and nuclei which represent the wastage from the lining epithelial found in the alveoli and ducts of the udder. They are, of course, not found in blood.

All gradations exist between evidently abnormal and strictly normal milk; and conditions that are significant in interpreting the phenomena of milk secretion are found in this intermediate region. Many samples that appear normal to the unaided senses show evidences of slight deviations from normal by chemical or microscopic analysis.

HISTORICAL.

Probably the first worker to show that milk from infected udders was abnormal in chemical composition and less acid in reaction than normal milk was Storch (1884, 1889). Similar results have been obtained by several later investigators; and Rullmann (1911) has shown that milk having a high leucocytic count likewise has a low titratable acidity. The later author sought the explanation of this lowered acidity in the presence of alkali-forming bacteria that more than counteracted the effect of the acid-forming streptococci, but could find nothing to confirm this view.

Fetzer (1912) also discusses the changes in milk caused by pathological conditions. He reaches conclusions essentially the same as those of Storch.

Hoyberg (1911), working with his rosolic acid-alcohol test for determining the reaction of milk, concludes that excessive numbers of leucocytes in milk are accompanied by a lessened acidity which he believes (as does Storch) is caused by the passage of blood serum into milk without change. He finds that, whereas a mixture of equal parts of cow blood serum and normal milk gave a deep red reaction with the rosolic acid-alcohol reagent, a mixture containing five parts of normal milk to one of blood serum gave a normal reaction for milk. He regards this as indicating that relatively large amounts of unchanged blood serum must pass into milk where the reaction is decidedly less acid than normal.

Hoyberg's test is made by adding 5.5 cc. of his rosolic acid-alcohol reagent to 5 cc. of milk in a test-tube. The color obtained is compared with the colors of a color chart. The reagent is prepared by adding 4.5 cc. of a 1 per cent alcoholic solution of rosolic acid to 5.0 cc. of 96 per cent alcohol. Though he gives no warning, care should be taken that the alcohol is acid-free.

Bahr (1913-14) has tried Hoyberg's test and reports that he has secured fairly satisfactory results with it in detecting cows giving milk with high leucocyte and bacterial content. He, like Rullmann, sought the explanation of the decreased acidity in the presence of alkali-forming bacteria, but without success. He comes to the conclusion that Hoyberg is mistaken in assuming that large quantities of unchanged blood serum are present in the less acid milk, showing that the addition of sufficient blood serum to cause the observed changes in reaction introduces an improbable amount of coagulable proteins. He seeks the explanation of the lessened acidity in the passage of tri-basic sodium phosphate from the blood into the milk without change into mono-basic phosphate.

Turning now to the papers dealing with the relation between the leucocytes and the streptococci, we find practically universal agreement that infections of the udder with pathogenic streptococci are accompanied by the presence of large numbers of leucocytes in the milk. This literature has already been reviewed (Breed, 1914) and need not be again discussed other than to point out that while Russell and Hoffmann (1907) found a practically constant relation between these two things, yet they noted

several instances where high cell counts occurred without detectable infection with streptococci. In the two cows the milk of which was studied during a lactation period by Hastings and Hoffmann (1909), there were consistent high counts of cells accompanied by a streptococcic infection. The latter, however, produced no evident change in the normal appearance of the milk. Likewise in the work on cell studies previously reported (Breed, 1914, p. 167), the history of the fluctuations in cell content of the milk of a cow that had recently freshened was followed for 24 days. In this case, though the milk contained many cells at some milkings, there was no detectable infection with streptococci. The milk was of normal appearance after the colostrum period had passed.

Some recent work by Cooledge (1918) suggests that some of the cases where high cell counts have been obtained in milk of normal appearance are caused by infections with *Bacterium abortus*. These organisms are not so readily recognized in milk as are the streptococci, and are now known to occur quite frequently in fresh milk. Purely physiological disturbances in the secretory processes such as occur during the colostrum period may also cause fluctuations in cell counts.

Technique Used.

In the present work the reaction of the milk has ordinarily been measured by the use of the brom-cresol purple test described by Baker and Van Slyke (1919). It was felt that this would be a more delicate indicator of changes of reaction of normal milk than the rosolic acid indicator used by Höyberg; but, in order to test the matter, a comparative trial was made of the two indicators with samples of fresh milk drawn from cows in the Station herd which were selected in such a way that a series of samples was obtained with varying reaction.

For comparison with the two indicators named, three other indicators were used, all of which are sensitive to changes where pH values are higher than those of strictly normal milk, but which are not so sensitive where the pH values are those of normal milk (6.50 to 6.60). These were saturated alcoholic solutions of rosolic acid, phenol red, and brom-thymol blue. In all cases except with Höyberg's reagent, one drop of the indicator was added to 3 cc. of milk. With the latter, the proportion was kept as indicated by the author, namely 5.5 cc. to 5 cc.

At the same time the reaction of the samples was determined electrometrically.

As a result of the color tests on the eleven samples (Table I), four observers were found to agree on the arrangement of the samples according to differences in shade of color. This sequence in color shades was found to agree with the sequence established electrometrically in all cases where the reaction fell within the known sensitive range of the indicator.

TABLE I.

Reaction of a Series of Milk Samples.

Results arranged in sequence according to pH values for comparison with the colors obtained with various indicators.

Sample No.	Reaction value *	Sequence as established by the shade of color of indicator.					Notes
		Brom-cresol purple †	Brom-thymol blue ‡	Phenol red §	Rosolic acid ||	Höyberg's reagent ||	
	<i>pH</i>						
1	6.51	1	1	1	1	3	Nos. 1 to 7 normal in appearance and from apparently normal udders.
2	6.53	2	1	1	1	4	
3	6.54	3	1	1	1	5	
4	6.58	4	1	1	1	2	
5	6.64	5	2	1	1	7	
6	6.73	6	3	2	2	1	
7	6.78	7	4	3	3	6	
8	6.87	8	5	4	4	8	Sample normal; but from a quarter previously affected with garget. From inflamed quarter. Normal in appearance. Similar to No. 9. From quarter badly affected with garget. Abnormal in appearance.
9	6.90	9	6	5	5	9	
10	6.95	10	7	6	6	10	
11	7.08	11	8	7	7	11	

* Determined electrometrically.

† Color change from light blue to dark purple-blue.

‡ " " " greenish yellow to green.

§ " " " yellow-orange to red.

|| " " " pink to dark red.

However, the curdling produced by the alcohol in Höyberg's reagent caused irregularities in color in the less sensitive range of rosolic acid (pH between 6.50 and 6.79). It was only samples showing greater pH values than this (Samples 8 to 11) that showed

a regular sequence in color change. All the latter samples were from quarters that were either inflamed at the time or had been affected with garget previously.

From these results it was concluded that whereas Höyberg's reagent was sufficiently sensitive to pick out milk that was decidedly less acid than normal, it was not a satisfactory test for the purposes in hand, nor as good for general use as the brom-cresol purple test.

Differential leucocyte and epithelial cell counts have been made by the method originally described by Prescott and Breed (1910). In making the counts, all the small cells bearing a close resemblance to mononuclear, polymorphonuclear, and polynuclear leucocytes were included in the one group, while all the large vacuolated cells of the colostrum corpuscle type and all the large separate nuclei probably originally derived from epithelial cells were counted in a second group. This classification was followed as it is *a priori* improbable that any close relation exists between the reaction of milk and the amount of epithelial cell debris present.

The presence or absence of streptococci has been determined in each case by a microscopic examination of the stained dried milk as freshly drawn. If this examination was negative, a second microscopic examination was made after incubating the milk sample for 24 hours at 37°C. Streptococci have been reported as present whenever it has been possible to find cocci in chains which consisted of more than four individuals to the chain. Some chains were short, containing scarcely more than the minimum number of organisms; but the majority were long; *i.e.*, contained twenty to thirty or more individuals in the chain.

No conclusions should be drawn concerning the number of samples in any class as the samples were taken from animals known to be infected with streptococci, or giving milk with a reaction less acid than normal in one or more quarters.

The samples were drawn aseptically from individual quarters of the udder and were examined for reaction at once. They were taken after the milking was approximately half completed. The animals in the Station herd are Jerseys, with some grade Jerseys, while the animals in the other herds were Holsteins mixed with common stock.

Data and Observations.

Observations were made of the reaction and cell and streptococcic content of 63 samples of milk from cows in the Station herd; and of 61 similar samples from animals in two herds in the neighborhood.

As it is difficult to pick out the relations existing between the reaction, cell content, and streptococci from the results as obtained, they have been arranged in Tables II, III, and IV in such a way as to contrast the reaction with the leucocyte content, the epithelium cell content, and the presence of streptococci. Finally, the averages of these tables have been combined in Table V for convenience in comparison.

Even a casual examination of the detailed results shows that a relation exists between the number of leucocytes present and the reaction of the milk. This appears in a more striking way in Table II in which the results are arranged according to a scale of decreasing acidity. From this it appears that the highest leucocyte count noted from milk with the reaction of Group 1 (pH values between 6.50 and 6.60) was 330,000 per cc., while the average count for the thirty-seven samples in this class was only 46,000. Fourteen of these samples contained so few leucocytes that none was observed in the microscopic examination of $\frac{1}{3,000}$ cc.

In the twenty-one samples in which there was a slight but perceptible darkening of the brom-cresol purple (pH values between 6.60 and 6.68), it will be noted that whereas four samples contained so few leucocytes that none was seen in the microscopic examination, two samples contained in excess of 1,000,000 per cc. (maximum 1,440,000). The average leucocyte content of the twenty-one samples was 215,000 per cc.

With certain exceptions to be noted presently, there is a gradual, though somewhat irregular, increase in the number of leucocytes with decreasing acidity as shown by the regular increase in the average leucocyte count for each group of samples. This reaches its climax in the ten samples of milk in which the pH values are greater than 7.00. In these the lowest leucocyte count was 1,980,000, and the highest, 40,900,000 per cc. The average count for this group was 16,800,000 per cc.

Two counts were so widely divergent from the usual conditions that they were not included in the averages. The two unusual samples fell in Group 5 (pH values 6.84 to 6.92). One gave a leucocyte count of 20,000,000 and the other 33,800,000 per cc.

TABLE II.

Comparison between the Reaction and the Leucocyte Content of Milk of Normal Appearance.

Leucocyte counts given in thousands per cc.

Group 1. pH 6.50-6.60.		Group 2. pH 6.60-6.68	Group 3. pH 6.68-6.76.	Group 4. pH 6.76-6.84.	Group 5. pH 6.84-6.92.	Group 6. pH 6.92-7.00.	Group 7 of Table III. pH 7.00+.
thousands	thousands	thousands	thousands	thousands	thousands	thousands	thousands
90	0	1,440	220	1,620	2,460	3,900	21,600
60	10	0	380	4,110	5,100	1,600	34,000
30	70	30	190	240	320	4,000	40,900
0	110	410	70	3,690	20,000	10,000	1,980
0	90	20	2,550	90	1,520	3,000	4,300
0	0	0	1,510	300	380	3,180	Innu-
120	0	0	0	270	8,100	1,740	merable.
0	180	250	360	360	33,800	7,380	4,000
30	0	60	120	2,580	540	8,400	7,800
0	30	40	1,020	120	16,500	3,000	15,300
30	30	110	2,040	300	1,770	5,000	21,000
0	330	160		1,120			
30	0	1,030		900			
0	0	220		510			
120	0	0		800			
110	120	60		810			
10		60		1,000			
40		60					
40		20					
10		180					
30		360					
Average	46	215	770	1,100	8,230 4,080*	4,650	16,800

* Two excessive counts omitted from the average.

These counts are both greatly in excess of the average count for samples in this group. In the first of these cases, a sample taken from the same quarter a few days previously had given an almost identical count (21,600,000 per cc.) with a less acid reaction (pH 7.00 +).

In spite of these and other less noticeable exceptions, the observations are in general accord with the theory that decreased acidity is correlated with increase in the number of leucocytes present in fresh milk. Minor irregularities are explainable by inaccuracies of technique, while some of the larger ones are undoubtedly due to the influence on the reaction of the production of acid from lactose by streptococci. No satisfactory explanation of these relations is evident if the leucocytic nature of the cells is denied as is done by Winkler (1908) and by Hewlett, Villar, and Revis (1909-1913).

The relation between the amount of cellular debris of epithelial origin and the reaction as shown in Table III does not appear to be as striking as that with the leucocytes. Where the results are arranged according to reaction and the cell counts averaged, it is evident that there is more epithelial cell debris in the samples with the lowest acidity. Yet the increase in amount of cell debris with decreasing acidity is not regular. This suggests that the relation between the two things is not a close one, and agrees with the conception that inflamed conditions are likely to cause a discharge of an increased but irregular amount of epithelial cell debris.

In considering the possible relation between the reaction and the presence or absence of streptococci, the conditions under which such a condition might exist should be kept in mind. The pathogenic streptococci are well known inciters of inflammatory processes in animal tissues, and are common causes of such troubles in udders. During any disturbance of this type in the udder, the leucocytes tend to congregate in large numbers. Both the leucocytes and an accompanying serous exudate probably pass through the glandular epithelium under these conditions. At first there would be little, if any, actual disorganization of the glandular epithelium but eventually, as shown in the excellent figures drawn by Ernst (1913), the lining of certain alveoli in limited areas would actually break down, thus allowing the direct entrance of lymph, or even blood serum, by the rupture of the walls of the vessels carrying these body fluids. In the later stages, this disorganization would involve large areas, even entire quarters of the udder. The secretion would no longer have the appearance of normal milk under such conditions.

During the period previous to the actual rupture of the epithelium and vessels, it seems probable that the normal life processes controlling the entrance and elaboration of the blood nutrients in the gland cells would be weakened or modified. A natural change would be for the readily dialyzable substances of the

TABLE III.

Comparison between the Reaction and the Epithelial Cell Content of Milk of Normal Appearance.

Epithelial cell counts given in thousands per cc.

Group 1. pH 6.50-6.60		Group 2. pH 6.60-6.68	Group 3. pH 6.68-6.76.	Group 4. pH 6.76-6.84.	Group 5. pH 6.84-6.92.	Group 6. pH 6.92-7.00.	Group 7. pH 7.00 +.
thousands	thousands	thousands	thousands	thousands	thousands	thousands	thousands
30	0	240	590	210	150	1,200	1,230
0	60	0	640	270	360	420	1,260
60	160	0	370	90	200	660	0
0	490	970	110	420	570	210	180
0	330	40	220	60	660	450	270
0	0	0	780	120	570		330
0	0	60	0	30	1,870		300
30	30	270	90	480	3,300		930
30	90	150	0	300	840		
60	0	120	570	12	390		
60	60	220	240	30			
30	0	420		120			
0	0	660		90			
10	60	490		60			
0	0	60		150			
580	0	60		180			
180		90					
190		90					
140		0					
70		30					
50		30					
Average	75	190	330	160	890	590	560

blood, such as the mineral salts, urea, glucose, and amino-acids to pass into the milk with the serous exudate in increased amounts without undergoing the usual processes of elaboration. However, the chemical findings previously reported (Van Slyke and Baker, 1919) indicate that even under these conditions the glucose is

transformed into lactose (see also Porcher, 1905). If, however, the mineral salts of the blood (especially sodium bicarbonate and basic phosphates) pass into the milk, they would reduce the hydrogen ion concentration, even though the remaining substances of the blood serum did not enter.

The entrance of some other substances in unaltered condition early in this process is indicated by the fact that fibrin is readily demonstrated by appropriate stains in the less acid milk. This would indicate that, under the intermediate conditions before there is actual entrance of unaltered serum, there is a considerable period during which there is an entrance of modified or partially elaborated serum.

Another factor having a direct influence on the hydrogen ion concentration which ought not to be overlooked is the formation of acid by the streptococci by the fermentation of glucose or lactose. From the fact that the reaction of the streptococcus-infected milk is less acid than normal, it is evident that there must be a surplus of the substances causing a reduction in hydrogen ion concentration. As long as the new materials are being secreted the acidity is ordinarily neutralized; but as soon as the milk is drawn the streptococcic fermentation quickly changes the reaction to an acid one. This was evident in several samples where flocculent masses of bacteria settled to the bottom of sample tubes to which brom-cresol purple had been added. Within 30 minutes acid areas showed about each of the flocculent masses.

Even a casual study of the detailed data shows that streptococci were usually present in those cases where there were excessive numbers of cells accompanied by decreased acidity. The correlation between decreased acidity and the presence of streptococci is shown clearly in Table IV. In this summary it will be seen that whereas only one sample out of thirty-six (3 per cent) with a normal reaction (pH values from 6.50 to 6.60) was found to contain streptococci, the percentage of streptococcic infection increased regularly with decreasing acidity. This reached its climax in Group 7 (pH values 7.00 +) all of which contained streptococci.

Certain exceptional conditions are worth a further word of explanation. The single sample of milk with normal reaction that contained streptococci contained so few of them that they did

not appear in a microscopic examination of the milk until after incubation for 24 hours at 37°C. The cell count was likewise zero for $\frac{1}{8,000}$ cc. Evidently the infection in this case was dormant or so localized that it did not affect the reaction.

TABLE IV.

Comparison between the Reaction and the Presence or Absence of Streptococci in Milk of Normal Appearance.

Group 1. pH 6.50-6.60.		Group 2. pH 6.60-6.68.	Group 3. pH 6.68-6.76.	Group 4. pH 6.76-6.84.	Group 5. pH 6.84-6.92.	Group 6. pH 6.92-7.00.	Group 7. pH 7.00 +.
-*	+	-	+	+	+	+	+
-	-	-	+	+	+	+	+
-	-	-	+	-	+	+	+
-	-	-	-	+	-	+	+
-	-	-	+	+	-	+	+
-	-	-	+	+	-	+	+
-	-	+	-	+	+	+	+
-	-	+	-	+	+	+	+
-	-	+	-	+	(?)	-	+
-	-	-	-	-	+	+	+
-	-	-	-	-		+	
-	-	-	+	-			
-	-	-	+	-			
-	-	-					
-	-	-					
-	-	-					
-	-	-					
-	-	-					
-	-	-					
-	-	+					
-	-	-					
-	-	-					
-	-	-					
Per cent present	3	19	54	62	60	91	100

* Streptococci present +, streptococci absent -.

The single sample in Group 6 (pH values 6.92 to 7.00) that showed no streptococcic infection was taken from an udder where all the other quarters were infected with streptococci, one of them giving abnormal gargety milk. The leucocyte count was high (1,740,000 per cc.) and the conditions indicate that the inflammation in the other quarters had influenced the secretion in the uninfected quarter.

In one of the samples of Group 5 (pH values 6.84 to 6.92) reported as negative for streptococci a question mark has been added because a sample taken from the same quarter a few days later contained streptococci. The other negatives in this group may likewise have been caused by failure to find the streptococci, or they may have been caused by infection with other pathogenic organisms. Some were from cows where streptococcic infections were present in other quarters, while some were from cows where no streptococcic infection could be detected with the technique used.

TABLE V.

Comparison between the Combined Averages of Tables II, III, and IV.

Group	1	2	3	4	5	6	7
pH values	6.50- 6.60.	6.60- 6.68.	6.68- 6.76.	6.76- 6.84.	6.84- 6.92.	6.92- 7.00.	7.00 +.
Average leucocyte count, thousands per cc.	46	215	770	1,100	4,080	4,650	16,800
Average epithelial cell count, thousands per cc.	75	190	330	160	890	590	560
Samples containing strep- tococci, per cent.	3	19	54	62	60	91	100

When the combined averages are compared as in Table V, it is seen that the conditions governing the reaction, presence of leucocytes, epithelial debris, and streptococci are all in harmony with the idea that decreased acidity is primarily caused by the entrance of the alkaline substances contained in the lymph and blood serum. It is not probable that entirely unaltered blood serum enters until the inflammatory processes have gone so far that there is actual rupture of the blood vessels. Accompanying the entrance of these alkaline substances there is a fairly regular increase in the entrance of leucocytes, and a less regular increase in the amount of epithelial debris. In a majority of the samples examined, the primary cause of these changes appeared to be an infection with streptococci.

CONCLUSIONS.

In the previous paper by Van Slyke and Baker (1919) it is suggested that decreased acidity of fresh milk is due to the direct filtration of blood serum into the milk as secreted. In support of this view it is pointed out: (1) that this view is in harmony with the changes in composition that accompany decreased acidity; (2) that it is in agreement with the hydrogen ion concentration of normal milk (pH values 6.50 to 6.60) and that shown by blood serum (pH about 7.60); and (3) that it harmonizes with an increased CO_2 content of the less acid milk, normal milk containing about 10 per cent by volume of CO_2 and blood serum, 65 per cent.

Further proof of the presence of blood serum was furnished by the presence of fibrin as shown by fibrin stains. This normal constituent of blood does not appear in normal milk.

The only observed chemical relation that was out of harmony with the view that unchanged blood serum caused the low acidity of certain samples of milk was the fact that no glucose could be demonstrated in several samples in which it should have been present in appreciable quantities if this were the case. At that time it was suggested that further investigations were desirable.

From the new data here given, and from histological and physiological considerations, it appears that a more exact statement of the case would be that the infection causes the entrance of a serous exudate derived by the gland cells directly from the lymph rather than from blood. This serous exudate is neither exactly like blood serum nor milk. When the infection has proceeded to the place that actual rupture of the vessels occurs then unchanged lymph and blood would enter. The modifications in the secretions may be due to a weakening of the secretory activity of the cells or the exudate may have a definite protective function against the bacterial infection, or both conditions may hold simultaneously.

The processes involved are so complicated that it is little wonder that the matter is not clear even with the data at hand. It seems quite probable, however, that the increased CO_2 content of the milk samples having a lowered acidity is correlated with the entrance of bicarbonate from the blood. The acidity of the milk

would also be lessened by the entrance of increased amounts of basic phosphates or even of albumins. Changes in the secretion of the milk in relation to these substances could easily explain the changes in reaction actually noted without assuming the entrance of excessive amounts of unchanged blood serum or lymph. While these chemical changes are still only partially understood, the data establish the fact that the modifications of the secretion are correlated with an increased entrance of the leucocytes into the lumina of the alveoli. Accompanying this change in the secretory processes there also seems to be an increasing amount of wastage from the glandular epithelium.

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RELATION OF UROCHROME TO THE PROTEIN OF THE DIET.

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The literature dealing with the specific yellow coloring matter of the urine, the urochrome of Thudichum and of Garrod, shows, in addition to a number of more or less effective methods of preparation, an almost equal number of theories as to the probable origin and significance of that body. Since 1798, when Fourcroy and Vauquelin (1) first attempted to connect the yellow color of the urine with the excretion of urea, various workers have speculated with different results as to its origin. For an excellent historical review of the subject up to 1907 the reader is referred to St. Dombrowski's paper (2). For the purposes of the present discussion it is necessary only to show the differences of opinion that exist with regard to the origin of urochrome by citing briefly the conclusions of some of the more recent observers. Thudichum (3), although at first in favor of Maly's (4) theory of the urobilin origin of urochrome, later expressed his doubts as to its accuracy; Garrod (5), on the basis of his active aldehyde reaction, thought urobilin to be its precursor; St. Dombrowski (2) held the body proteins responsible for its appearance, and Weisz (6), as a result of very extensive investigations, concluded that urochrome is an "Abbauprodukt des Zellstoffwechsels" and thought that he had in its excretion a measure of the cell metabolism of the body; Klemperer (7), in 1903, made the following statement: ". . . at present I am inclined to believe that urochrome is a direct derivative of the blood pigments and is synthesized by the kidney," adding further that "an influence of the diet upon the excretion of urochrome has never been observed." The last statement is important here not only because it is the only positive statement which can be found in the literature with regard to the effects of the diet, but also because the present investigation shows it to be erroneous. Palmer and Cooledge (8), in a thorough examination of Garrod's results, state that urochrome probably originates from the blood rather than from the bile. No conclusions can be drawn from this work (referring to their own work on the identity of lactochrome with urochrome) as to whether urochrome is a decomposition product of protein or of blood pigment.

The present investigation was undertaken at the suggestion of Professor W. R. Bloor, with the intent of correlating the facts

brought out by previous observers and, perhaps, to establish more firmly the origin of the substance in question.

The thought that the protein intake may in some measure be responsible for the color of the urine seemed a promising one and was followed up with a series of experiments in variations of protein intake. The method of procedure was as follows. A 24 hour sample of urine was collected and a small portion of it filtered and compared in the Duboscq colorimeter with an arbitrary standard of 3.2 mg. of Bismarck brown and 8 mg. of Echtgelb Y¹ in 1 liter of water. The color corresponded closely to that of the normal urine, and a value of one unit per cc. was assigned to it. Another determination was made by adding 5 cc. of a 20 per cent solution of lead acetate to 25 cc. of the urine and comparing the filtrate with another arbitrary standard of 3 mg. of Echtgelb Y in 1 liter of water. In this manner two determinations were made of each 24 hour sample, one on the total color of the filtered urine, and another on the urine from which the proteins and such colors as urobilin and uroerythrin had been largely removed by precipitation with lead acetate, and which contained, therefore, urochrome as the principal coloring matter. In calculating the color units of the precipitated urine, due allowance was made for the dilution with lead acetate.

The results of the experiments are contained in Tables I to VI.

From these tables it is evident that protein may influence, to a remarkable extent, the daily urochrome output. On a low protein diet the output of urochrome was reduced to less than one-half its normal amount. It is probable that the amount of urochrome which still remained in the urine after several days of low protein diet is due, in part at least, to the protein products of the cell metabolism. A diet of carrots, following a low protein diet, raised the urochrome output slightly (Table IV), due, perhaps, to the consequent slight increase in protein intake, but did not raise it as high as should be expected if such colors as carotin or xanthophyll were concerned with urochrome excretion. Table III shows that the amount of daily urochrome is perceptibly raised by a high protein diet; it is, however, also apparent that this increase is not proportional to the decrease which

¹ The dyes were obtained through the kindness of H. A. Metz and Company, San Francisco.

may be obtained on a low protein diet. This failure to increase the excretion of urochrome to a more marked extent may be caused by the inability of the body to deal with more than a certain limited amount of that substance. A gelatin diet, preceded and followed by a low protein diet, showed no increase (Table V) in urochrome excretion, probably because of the absence of the color-producing groups (aromatic series) in this

TABLE I.
Normal Protein Diet (10 Gm. of N).

24 hr. volume.	Color units.	
	Filtered urine.	Lead acetate urine.
cc.		
1,100	1,060	1,146
1,150	1,287	1,202
1,300	1,277	1,115
1,020	1,032	1,035
925	1,138	1,008

TABLE II.
Low Protein Diet (6 Gm. of N).

24 hr volume.	Color units.	
	Filtered urine.	Lead acetate urine.
cc		
1,120	1,077	632
1,000	961	678
1,290	993	666
750	902	563
810	838	540

incomplete protein. In order to determine whether the urochrome excretion was constant from hour to hour, an examination of 2 hour samples of a high protein urine was made. Table VI shows that the output is variable and may in one 2 hour period be three times greater than in the preceding period.

The next logical step in this examination is, of course, the determination of the particular group or groups within the protein molecule to which this color is due. Lack of time has, unfortunately, so far prevented such an investigation. Some pre-

TABLE III.
High Protein Diet (14 Gm. of N).

24 hr. volume.	Color units.	
	Filtered urine.	Lead acetate urine.
<i>cc.</i>		
1,305	1,274	1,291
1,440	1,377	1,312
1,255	1,265	1,308
1,350	1,312	1,418
1,190	1,263	1,380

TABLE IV.
Carrot Diet Following Low Protein Diet.

24 hr. volume.	Color units.	
	Filtered urine.	Lead acetate urine.
<i>cc.</i>		
1,050	1,078	737
980	1,040	720

TABLE V.
Gelatin Diet Preceded and Followed by Low Protein Diet.

24 hr. volume.	Color units.		Total nitrogen.
	Filtered urine.	Lead acetate urine.	
Low protein diet.			
<i>cc.</i>			<i>gm.</i>
1,125	1,071	581	5.84
625	1,136	511	4.83
Gelatin diet.			
925	1,045	508	8.11
Low protein diet.			
840	996	523	6.02

liminary experiments in this direction led, however, to the discovery of a body in peptone (also in casein, but not in gelatin) which in every way corresponds to Garrod's urochrome and, incidentally, to Palmer and Cooledge's lactochrome. The method of preparation is essentially the same as that used by these workers in the preparation of urochrome and lactochrome.

TABLE VI.
High Protein Diet in 2 Hr. Samples.

Time.	24 hr. volume.	Color units.	
		Filtered urine.	Lead acetate urine.
	cc.		
8.10 a.m.	259	145	192
10.12 "	150	125	125
12.2 p.m.	175	110	113
2.4 "	100	160	188
4.6 "	70	85	61
6.8 "	110	104	195
8.8 a.m.	450	545	391
24 hrs.	1,305	1,274	1,291

A solution of 50 gm. of peptone in 100 cc. of water (with casein a preliminary digestion with HCl was necessary) was saturated with solid ammonium sulfate and filtered. The color was extracted from the filtrate by 95 per cent alcohol, which rose to the top as a highly colored layer and was syphoned off. The alcohol extract was poured into an equal volume of water and again extracted by saturation with ammonium sulfate. It was then evaporated on the steam bath after having first been cooled on a mixture of salt and ice to crystallize out most of the ammonium sulfate which had dissolved in the alcohol. After the product so obtained in the desiccator was dried, it was rubbed up in a mortar and placed in absolute alcohol over night. The absolute alcohol extract was removed next morning and the substance again treated with absolute alcohol. The two extracts were combined and the coloring matter was precipitated out of solution by addition of several volumes of ether.

The body so produced gave all the tests for urochrome (except Garrod's aldehyde test, which could not be applied because lack of time prevented the production of "active" aldehyde), which Palmer and Cooledge used to prove the identity between that substance and lactochrome. It is prepared by essentially the

same method; the solubility in water, alcohol, ether, chloroform, acetone, and benzene is the same; it is precipitated out of its water solution with silver nitrate, mercuric nitrate, and phosphotungstic and phosphomolybdic acids, and is not precipitated by ammonium sulfate or lead acetate. With a pine-splinter moistened with HCl it gives a striking pyrrol reaction, and its bromine derivative shows essentially the same characteristics as Salomonsen's (9) bromourochrome and Palmer and Cooledge's bromolactochrome.

If, in addition to the fact that the chemical reactions of this body—which we may call “protochrome,” at least until its nature is more fully established—correspond in every way to urochrome, it is considered that a low protein (low protochrome) diet reduces the output of urochrome more than 50 per cent, the conclusion that the two bodies are identical seems reasonable.

SUMMARY.

1. A low protein diet has been found to reduce the daily urochrome excretion markedly. A high protein diet increases the excretion perceptibly. Gelatin or carrots when taken in the diet have no effect on the output.

2. A new body, protochrome, the chemical reactions of which are identical with those of urochrome, can be produced from some of the proteins.

3. All evidence points to the fact that urochrome, lactochrome, and protochrome are identical and, at least to a large extent, are derived from the food proteins.

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A CONJUGATED NUCLEIC ACID OF PANCREAS.

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A recent preliminary communication by Feulgen¹ on a conjugated nucleic acid of pancreas prompts me to publish my own results on the same subject.

Feulgen prepared a nucleic acid from pancreas by enzymatic digestion of β -nucleoprotein. This acid could be split into phosphoric acid, levulinic acid, furfurol, thymine, cytosine, guanine, and adenine. He found that an alkali salt of guanylic acid could be precipitated with sodium acetate after digestion in alkaline solution. The nucleic acid was dextrorotatory. From these data Feulgen assumes his nucleic acid to be of a molecular composition between guanylic acid and tetranucleotide, and calls it "Guanyl-nucleinsäure."

As early as January, 1919, I isolated and described a "Guanyl-nucleinsäure" (Feulgen). In January of the same year the results were presented in a manuscript to the authorities entrusted with the appointment of a chemist at the Caroline Institute. I did not wish to publish my results, because of the incompleteness of the investigation at the time.

My results are essentially in accord with those of Feulgen, and the confirmation seems to be of sufficient value to justify publication.

Following is a summary of the most important of my results, up to January, 1919.

The method of preparing the nucleic acid had been worked out in the form described below.

¹ Feulgen, R., *Z. physiol. Chem.*, 1919, cvii, 147.

The calcium and sodium salts and the corresponding free acid had been analyzed. I had determined the ratio $\frac{N}{P}$ for the calcium salt as 1.9. After hydrolysis guanine, adenine, thymine, cytosine, and pentose were found. The ratio $\frac{\text{guanine}}{\text{adenine}}$ was determined to be about 3.

After an alkaline solution of the sodium salt of the nucleic acid had been warmed, cooled, and neutralized with acetic acid, a nucleic acid was precipitated, which could be identified as guanylic acid. A nucleic acid remained in the solution, which I could not at that time characterize. By determination of the alterations of the hydrogen ion concentration, the conductivity, and the freezing point after warming with a solution of caustic potassium hydrate, it was shown that acid groups had been freed; *i.e.*, that hydrolysis had taken place.

In the β -protein of pancreas (prepared according to Hammarsten) the ratio $\frac{\text{guanine}}{\text{adenine}}$ was stated to be about 3.

In the following pages the data, above summarized (collected during the year 1918), are reported together with the results of subsequent experiments.

The starting point of the present work was an attempt to isolate and fractionate the natural compounds of proteins and nucleic acids (nucleoproteins, nucleins) from pancreas, and then to produce nucleic acids from the different fractions. Different investigators have been looking for a third single nucleic acid of the type of the guanylic and inosinic acids, and I hoped to make progress in this field.

To this purpose dry pancreas was extracted with cold, dilute hydrochloric acid (0.06 N). From the undissolved matter the supposed nucleins were dissolved with alkali at a temperature of 0°C. and then precipitated with hydrochloric acid. The precipitate was purified by means of alternate dissolving and precipitating, and then dried with alcohol and ether.

The preparation dissolved perfectly clear on addition of alkali while the reaction was still slightly acid. For the sake of brevity I am going to call a neutral solution of the preparation in alkali "nuclein solution."

Lengthy attempts to get a constant fraction by means of salting out the nuclein solution with different neutral salts did not give satisfactory results. The highest fractions with ammonium sulfate showed, however, something of interest. From 80 per cent saturation with this salt up to complete saturation I got a precipitate which was easily soluble in water and which was precipitated by acids. It did not give any biuret reaction, and had (dried in the air) a high percentage of phosphorus (7.3 per cent). After hydrolysis with sulfuric acid a strong reaction for purine bases was noted. A splitting of nucleic acid-protein links had accordingly occurred, from the action of either the hydrochloric acid or the ammonium sulfate. This nucleic acid was not further investigated. The yield was very small, and in the meanwhile I had found that a nucleic acid could be isolated in ample quantities directly from a neutral nuclein solution by precipitation with calcium chloride. This calcium salt of nucleic acid, which was slightly soluble in water, was purified in different ways (see below), and from it the free acid and a calcium-sodium salt were prepared. All three preparations showed a ratio $\frac{N}{P} = 1.88$.

For an ideal tetranucleotide the ratio $\frac{N}{P}$ is = 1.69, and for the guanylic acid, = 2.26. A combination of 2 molecules of guanylic acid with 1 molecule of tetranucleotide would give the ratio $\frac{N}{P} = 1.88$.

By warming the solution of the sodium salt of the nucleic acid with 1 per cent sodium hydroxide, the hydrogen ion concentration and the electrical resistance were raised, while the freezing point remained unchanged—positive signs of an hydrolysis with the forming of acid groups.

After neutralization of the hydrolyzed solution, a substance was precipitated, which could be identified as guanylic acid.

From these results it appears probable that the substance analyzed by me is composed of guanylic acid and tetranucleotide, united in genuine chemical combination. Possibly 2 molecules of guanylic acid and 1 molecule of tetranucleotide are here bound together.

A more complete description of the experiments follows.

EXPERIMENTAL.

Pieces of pancreas from cattle were washed *in situ* immediately after slaughter, via arteria pancreatica with isotonic salt solution in order to get rid of the main part of the blood. The pieces were then put into a vessel which was surrounded by a freezing mixture. On arrival at the laboratory they were freed from fat and lymph tissue, ground to a pulp, and put into 96 per cent alcohol. The alcohol was pressed out after 1 hour and the mass again mixed with 96 per cent alcohol. In this way the mass was extracted with 96 per cent alcohol three more times (after 3, 12, and 24 hours). Then it was treated twice with ether, dried in the air, and put into a ball-mill. The treatment with alcohol and ether is necessary for subsequent attainment of a filterable extract on treatment with sodium hydroxide.

600 gm. of the dusty, gray-white powder were extracted, with stirring, with 4 liters of 0.06 N hydrochloric acid for 24 hours at 6°C. The insoluble matter was then pressed to a solid cake, mixed with 1 liter of cold water, and again sharply pressed from the liquid. The solid pulp was ground with 2 liters of water at 0°C. and then, during cooling of the extraction vessel and stirring, mixed with a 0.06 N solution of sodium hydroxide at 0°C. in small portions. In these operations care was taken that the temperature did not exceed 0.5°, and that the mixture in the extraction vessel after each addition of sodium hydroxide did not give more than a weak bluish violet color with neutral litmus paper (about the same reaction which is obtained from a mixture of three parts of 0.1 N primary and seven parts of secondary phosphate). In the course of 4 hours 4,400 cc. of a 0.06 N solution of sodium hydroxide were added. The liquid, which then showed a neutral reaction, was strained through a closely woven linen cloth. The filtrate was strongly turbid and of a brownish yellow color. It was at once thrown onto a double layer of folded filter paper in a room cooled to 0°C. The filters were changed every day and new ones put on. In this way the whole extract could be filtered in 72 hours. The filtrate was straw-colored and nearly clear, but showed when standing during the filtration a slight turbidity. This was removed by a second filtration, which required but a few minutes. The filtrate was now entirely clear and had no foul or musty odor. To each liter were added 10 cc. of 10 per cent hydrochloric acid. Thereupon an abundant, coarsely flocculent, white precipitate appeared, which was centrifuged and washed several times in the centrifuge with 1 per cent acetic acid. The precipitate was then stirred with 1 liter of water at 0°, and mixed with a dilute solution of sodium hydroxide to neutral reaction. The liquid, which was somewhat turbid, was filtered once more at 0°C., the nearly clear filtrate precipitated with 10 cc. of 10 per cent hydrochloric acid, the precipitate washed repeatedly in the centrifuge with 1 per cent acetic acid, and then six times with 96 per cent alcohol. Finally it was washed twice with absolute alcohol, and then several times treated with ether, and each time was rapidly filtered on a suction filter. The preparation had, dried in the air, a nearly

white color. It was apparently neither hygroscopic nor soluble in water, but easily soluble in alkali, even at acid reaction. A 2 per cent solution was quite clear, had a yellowish color, and was precipitated as coarse flakes by acetic acid, hydrochloric acid, and calcium chloride.

A neutral solution of the preparation (for the sake of brevity in the following called "nuclein") showed at room temperature no tryptic activity. A nuclein solution, which had stood 24 hours at 20°, showed no alteration in the formol titratable nitrogen.

Destruction of the trypsin is effected by the action of 0.06 N hydrochloric acid on dry pancreas, as is shown by Table I.

After 24 hours (Nos. 1 to 6 at 6°C., No. 7 at 37°) Nos. 2 to 6 were neutralized with sodium hydroxide. To Nos. 1 and 7 the same amounts of NaCl were added that were generated in the other experiments. All the experiments were carefully brought to the same reaction to litmus. Nos. 1 to 4 and 7 were boiled for 5 minutes, cooled, and water was added to bring the solution up to 200 cc. Having stood for 24 hours at 6°, these samples were filtered and the nitrogen was determined, Nos. 5 and 6 were neutralized after the first 24 hours, 10 gm. of fibrin were added, and the mixture was once more digested for 24 hours at 37° and 6°C., respectively, then boiled for 5 minutes, brought to 200 cc. with water, filtered, and the nitrogen was determined in the filtrates. The analytical results are, of course, to be regarded as approximate.

Dry pancreas, fibrin, and hydrochloric acid gave 19 mg. of nitrogen. The result, No. 2 + No. 3 = 18.3, corresponds well to this. No tryptic digestion could have taken place here. The nitrogen is derived directly from water-soluble nitrogenous compounds. In No. 1, 52 mg. of N were found; i.e., about 30 mg. were brought into solution through the influence of trypsin. Nos. 5 and 6 showed clearly that the influence of trypsin was neutralized through the treatment with hydrochloric acid. Only 2 to 4 mg. could be attributed to digestion, amounts which surely lay within the limits of error. The digestion of No. 7 yielded about 320 mg. This shows clearly—especially compared with the fact that no difference between the nitrogen values in Nos. 5 and 6 was noted—that the 24 hours influence of the 0.06 N hydrochloric acid at 6° had completely destroyed the trypsin.

In the filtration of the alkaline extract of pancreas, formol titrations were made in the filtrate every 12 hours. The amino nitrogen thus titrated did not increase. This shows that no breaking of peptide linkings had taken place. With the precautions which were taken in the preparation of the dry pancreas, I consider the risk of autodigestion of the pancreas brought to a minimum. Through the treatment with hydrochloric acid the trypsin was destroyed and the nuclein, which was free from active trypsin, could not be a product of enzymatic digestion.

In the nuclein (dried in the air), nitrogen and phosphorus were determined. Found: 17.09 per cent N; 5.61 per cent P.

Part I of the same preparation was dissolved in a solution of sodium hydroxide and Part II in ammonia. The solutions were precipitated with

a small surplus of hydrochloric acid, the precipitates washed with water, and dried with alcohol and ether. Found: (Part I) 19.09 per cent N; 4.69 per cent P; (Part II) 17.07 per cent N; 5.15 per cent P.

Also in preparations from different experiments (with the same method) the phosphorus varied between 4 and 5 per cent; the nitrogen, however, was constant. Considering that the phosphorus showed a great variation in nucleoproteins and nucleic acids, and the nitrogen a rather small one, it was probable that the preparation was composed of a mixture of protein-rich and protein-poor nucleins with perhaps nucleic acids.

A neutral 2 per cent nuclein solution in sodium hydroxide gave a strong biuret reaction with a bluish violet color, and was incompletely precipitated by acetic acid, hydrochloric acid, and alcoholic hydrochloric acid. Ammonium sulfate precipitated at a saturation of 25 per cent. The precipitation increased up to complete saturation. Calcium chloride and barium chloride gave strong precipitates.

The precipitation with CaCl_2 was more closely investigated. It appeared that maximum precipitate occurred in a 2 per cent nuclein solution on the addition of 0.5 per cent CaCl_2 . At this point 23 per cent of the total amount of nitrogen was precipitated. Adding more CaCl_2 (up to 5 per cent CaCl_2 in the solution) gave no more precipitation.

Precipitation was equally complete, whether the nuclein solution was weakly acid or weakly alkaline. The calcium precipitate (in the following called Precipitate A) was washed several times with water, then repeatedly ground with alcohol, and treated on a suction filter, until no reaction for Ca or Cl was given by 50 cc. of the filtrate after the evaporation of the alcohol.

0.5 gm. of the air-dried preparation was gently ignited and the residue extracted with nitric acid. The filtrate showed no trace of chloride, but large amounts of calcium.

A neutral nuclein solution in ammonia was precipitated with calcium chloride and the precipitate washed and dried as above. 1 gm. of the preparation was dissolved in 25 cc. of a 1 per cent Na_2CO_3 solution, and the ammonia nitrogen determined according to Folin. Found: 0.9 mg. N.

When Precipitate A was stirred into water, the solution reacted neutral to litmus, and on addition of one drop of 0.1 N solution of sodium hydroxide to 10 cc. the reaction turned visibly alkaline.

From the filtrate of the calcium precipitate a precipitate was obtained with alcohol, which also behaved as a neutral calcium salt. This substance will be described in a second communication.

Neutral sodium and ammonium salts of the nuclein gave with CaCl_2 (BaCl_2 acted similarly) a double conversion, generating neutral calcium salts and sodium and ammonium chlorides, respectively.

Precipitate A dissolved easily in a solution of 1 per cent sodium hydroxide. Yet this solution showed slight biuret reaction. It was stirred several times in 2 per cent acetic acid and washed in the centrifuge. Large amounts of calcium acetate went into solution, but it was not possible to remove all the calcium in this way. When Precipitate A had been ex-

tracted three times with 2 per cent acetic acid, it nevertheless was dissolved completely in a solution of sodium hydroxide at neutral reaction. This solution was precipitated with a solution of CaCl_2 , and the precipitate washed four times with 1 per cent CaCl_2 solution in the centrifuge. The precipitate gave now, dissolved in a solution of sodium hydroxide, no trace of biuret reaction. The calcium chloride was completely removed by washing with 96 per cent alcohol and the substance, after being treated with ether, was dried in the air. The preparation (A_1) was partly used for analysis and partly for further purification. From A_1 —through extracting with acetic acid, dissolving with sodium hydroxide, and precipitating with calcium chloride (93 per cent of the nitrogen was precipitated)—another preparation (A_2) was obtained (precipitated in all four times with CaCl_2). One part of A_1 was treated with acetic acid, dissolved at neutral reaction with a solution of sodium hydroxide, and precipitated with two volumes of alcohol, which contained 0.2 per cent HCl . The precipitate was quickly centrifuged and washed twice with water and then several times with alcohol. After a treatment with ether it was dried in the air. The preparation (B_1) was partly used for analysis and partly further purified. By dissolving and precipitating twice with hydrochloric alcohol a preparation (B_2) was obtained.

The calcium salt of the nucleic acid was easily soluble in a solution of sodium chloride. One part of A_2 was stirred with a 10 per cent solution of sodium chloride. The solution was filtered from a very small dark-colored residue and then precipitated with four volumes of alcohol. The precipitate was washed many times with alcohol and then treated with ether and dried in the air. The white powder was dissolved in water and once more precipitated with alcohol, washed with 96 per cent alcohol and ether, and dried in the air. The preparation was called C.

Accordingly preparations were obtained as recorded in Table II.

50 gm. of nuclein were hydrolyzed with 5 per cent sulfuric acid for 5 hours at 100°C . The solution was filtered and the amount of sulfuric acid reduced with ammonia to 1 per cent. The solution was saturated while still hot with ammonium sulfate, and the precipitated, dark-colored albumoses were separated by filtration. The precipitate was dissolved in hot 1 per cent sulfuric acid, the solution saturated with ammonium sulfate, filtered, and the precipitate washed with a saturated solution of ammonium sulfate. The two filtrates were united.

(By direct experiments I have made sure that the purine bases in hydrolyzed albumin solution treated by this method remain quantitatively in the filtrates, and that after dilution with the same volume of water they are quantitatively precipitated with an ammoniacal silver solution.)

The filtrates were straw-colored. They were diluted with water, made strongly ammoniacal, and precipitated with an ammoniacal silver solution. The silver precipitate was put on a suction filter, washed, and the purine bases were then fractionated from it in the usual way.² The

² Steudel, H., in Abderhalden, E., *Handbuch der biochemischen Arbeitsmethoden*, Berlin and Vienna, 1910, ii, 585.

guanine was precipitated twice with ammonia, dissolved in a solution of sodium hydroxide, and precipitated with acetic acid. The adenine picrate was precipitated twice from the solution in sodium hydroxide by adding the calculated amount of hydrochloric acid. In the filtrate after the first precipitation of the adenine as picrate such a small amount of purine bases was left that xanthine and hypoxanthine could not be present. After being dried over sulfuric acid at room temperature the preparations were analyzed.

Guanine: 0.0476 gm. corresponded to 21.98 cc. N/14.01 $\text{Na}_2\text{S}_2\text{O}_3$ solution (Kjeldahl).

N: found 46.18 per cent; calculated 46.36 per cent.

Adenine-picrate: 0.3950 gm. was dissolved in alkali, the solution acidified with sulfuric acid, and the picric acid completely shaken out with ether. The ether was shaken with water and the nitrogen determined in tenths of the aqueous extracts. They corresponded to 7.60, 7.59, and 7.60 cc. N/14.01 $\text{Na}_2\text{S}_2\text{O}_3$ solution (Kjeldahl).

N: found 19.24 per cent; calculated for adenine, 19.24 per cent.

The preparation melted in 5 seconds at 280°C .

30 gm. of A_1 were hydrolyzed as above with 5 per cent sulfuric acid, and the solution was filtered and extracted with ether.

From the ether extract levulinic acid in small amounts could be isolated as silver salt.

0.1769 gm. gave 0.1130 gm. AgCl .

Ag: found 48.08 per cent; calculated 48.43 per cent.

The rest of the hydrolyzed solution was analyzed in the usual way for purine and pyrimidine bases. Guanine, adenine, and picrate of cytosine were isolated. The thymine fraction was lost. Yet, from the ether extracts typical thymine crystals were found (microscopic observation), and A_1 as well as B and C gave, when treated by Kossel and Neumann's method,³ crystals that sublimed when heated, and which were soluble in alcohol and water.

Guanine (dissolved twice in a solution of sodium hydroxide, precipitated with acetic acid, and dried over sulfuric acid *in vacuo* at room temperature): 0.0261 gm. corresponded to 12.09 cc. N/14.01 $\text{Na}_2\text{S}_2\text{O}_3$ solution (Kjeldahl).

N: found 46.32 per cent; calculated 46.36 per cent.

Adenine picrate (once recrystallized and dried as above): from 0.4731 gm. the picric acid was removed and the nitrogen analyzed in tenths of the solution according to Kjeldahl. Two portions corresponded to 9.05 and 9.10 cc. N/14.01 $\text{Na}_2\text{S}_2\text{O}_3$ solution.

N: found 19.18 per cent; calculated for adenine 19.24 per cent.

The preparation melted in 5 seconds at 281°C .

Cytosine picrate (once recrystallized and dried as above): 0.1008 gm. gave 0.1295 gm. CO_2 and 0.0223 gm. H_2O (Dennstedt); 0.0469 gm. corresponded (after shaking out the picric acid) to 5.75 cc. N/14.01 $\text{Na}_2\text{S}_2\text{O}_3$ solution.

³ Kossel, A., and Neumann, A., *Ber. chem. Ges.*, 1893, xxvi, 2753.

	Found. per cent	Calculated. per cent
C.....	35.05	35.26
H.....	2.48	2.37
N.....	12.26	12.36*

* Calculated upon cytosine.

About 4 gm. of A₁ were dissolved in a solution of sodium hydroxide and the nitrogen was determined in a part of the solution. The total amount of N was 763.5 mg. The solution was neutralized and hydrolyzed for 5 hours with 5 per cent sulfuric acid at 100°C. After neutralization the solution was filtered and precipitated with an ammoniacal silver solution. The precipitate was washed and decomposed with hydrochloric acid. After a second precipitation and decomposition the hydrochloric acid filtrate was brought to dryness three times *in vacuo*, water being added after each concentration. The residue was dissolved in hot water, and the warm solution (150 cc.) was mixed with ammonia up to 3 per cent. After standing for 24 hours in a closed vessel the guanine was removed by filtration, washed with 30 cc. of ammonia, and dissolved in a solution of sodium hydroxide. The solution was made acid with sulfuric acid, and the guanine precipitated with ammoniacal silver solution (guanine fraction). Filtrate and washings from the precipitate of the guanine with 3 per cent ammonia (180 cc.) were precipitated with ammoniacal silver solution (adenine fraction).

The two silver precipitates were decomposed with hydrochloric acid, and two samples taken from each of the filtrates. From the guanine solution (300 cc.) 2 samples of 10 cc. were taken, and from the adenine solution (100 cc.) also 2 samples of 10 cc. The four samples were precipitated with ammoniacal silver solution, the precipitates washed with 1 per cent ammonia, suspended in water, and, after the addition of sodium carbonate, the ammonia nitrogen was completely removed according to Folin. The nitrogen in the residues was determined according to Kjeldahl. The samples of the guanine fraction corresponded to 13.15 and 13.19 cc., those of the adenine fraction to 14.72 cc. and 14.66 cc. N/14.01 Na₂S₂O₃ solution.

According to Wulff,⁴ 0.015 gm. guanine is soluble in 100 cc. of 3 per cent ammonia. A corresponding correction for the guanine, which remained in the filtrate from the first guanine precipitate, was therefore necessary. The 180 cc. would, according to Wulff, contain 12.52 mg. of nitrogen as guanine. Out of the 763.5 mg. of nitrogen were then found 407.6 mg. as guanine and 134.4 mg. as adenine. The ratio $\frac{\text{guanine}}{\text{adenine}}$ was therefore $\frac{0.8792}{0.2592} = 3.39$. The amounts of nitrogen (541 mg.) found in the purine

⁴ Wulff, C., *Z. physiol. Chem.*, 1893, xvii, 505.

bases corresponded to about 71 per cent of the total amount of nitrogen (763.5 mg.). Of course, the values found for guanine and adenine cannot be regarded as exact. They give, however, an approximate idea of the proportion between guanine and adenine.

Guanine and adenine (according to analysis, respectively 46.20 and 51.86 per cent N, Kjeldahl) were each dissolved by sulfuric acid. The guanine solution contained in all 40.07 mg. of N and the adenine solution 29.0 mg. of N. The solutions were mixed and sulfuric acid was added up to 5 per cent. The mixture was heated 5 hours at 100°C. Then guanine and adenine were separated, as above, after precipitation as silver compounds.

TABLE I.

Time 2 × 24 hrs.

No.	Dry pancreas.	Fibrin.	Liquid.	Nitrogen in the filtrate.
	gm.	gm.	cc.	mg.
1	0.5	10	150 water.	51.6
2	0.5		150 0.06 N HCl.	8.5
3		10	150 0.06 N HCl.	9.8
4	0.5	10	150 0.06 N HCl.	19.1
5	0.5		150 0.06 N HCl.	23.0
6	0.5		150 0.06 N HCl.	21.0
7	0.5	10	150 water.	342.0

Found: 38.07 mg. guanine N and 26.14 mg. adenine N. $\frac{\text{Guanine}}{\text{Adenine}} = \frac{0.0864}{0.0504} = 1.71$. Calculated: $\frac{0.0864}{0.0559} = 1.55$. Losses = 7 per cent of total N.

A number of fractions of the purine bases were made in the different preparations. The course of the analysis was the same as described above. I also tried to determine the proportion between guanine and adenine in Hammarsten's β -protein and Umber's⁵ protein. The silver compounds of the purine bases from these substances were precipitated from the hydrolyzed solutions, after saturation with ammonium sulfate.

⁵ Umber, F., *Z. klin. Med.*, 1900, xl, 464.

TABLE II

Preparation.	Precipitated with.	Color.	Solubility.	Precipitability.
Nuclein.	HCl twice.	White with a slight tendency to gray.	Nearly insoluble in water; easily soluble in alkali.	With acetic acid, HCl, and CaCl_2 in complete precipitations
Neutral Ca salt. A ₁ A ₂	CaCl_2 twice. CaCl_2 four times.	White with a slight tendency to gray.	Nearly insoluble in water, 2 per cent acetic acid, and 0.2 per cent HCl; clearly soluble in 10 per cent NaCl solution.	
Free acid (contained some lime). B ₁ B ₂	HCl and alcohol once. HCl and alcohol thrice.	White with a slight tendency to gray.	Insoluble in water; easily soluble even at acid reaction in NaOH. 2 per cent solution straw-colored; a 10 per cent solution dark brown.	With acetic acid only at about 5 per cent opalescence in the solution. HCl and CaCl_2 solution precipitated nearly quantitatively.
Double salt of Ca and Na. C	Alcohol twice.	Quite white.	Easily and quite clearly soluble in water and 20 per cent sodium acetate. 5 per cent solution straw-colored.	Acetic acid precipitated only at 10 per cent acid in the solution; HCl and CaCl_2 solution precipitated nearly quantitatively.

The total amount of basic nitrogen was also determined directly. After hydrolysis, as described above, the silver compounds of the purine bases were precipitated, the precipitates washed, decomposed with HCl, the filtrates evaporated to dryness three times *in vacuo*, the residues dissolved in water once more, precipitated with silver from the ammoniacal solutions, the precipitates washed with 1 per cent ammonia, suspended in a solution of sodium carbonate, all the ammonia nitrogen was expelled, and the nitrogen determined in the residues according to Kjeldahl.

10 gm. of B₂ (p. 249) were (according to Steudel) added to 20 cc. of nitric acid at 0°C. and of a specific gravity of 1.02. After standing for 6 days at 0°C. the purine bases were fractioned in the usual way. The adenine was twice fractioned from guanine with ammonia. The guanine and the adenine picrate were once precipitated and weighed, without further cleaning after drying over sulfuric acid *in vacuo* at room temperature. Found: guanine, 1.2087 gm. (without correcting for the guanine, dissolved in the ammoniacal mother liquor); adenine picrate 1.0894 gm. (corresponding to 0.4041 gm. adenine).

- A₁. About 4 gm. gave 407.6 mg. guanine N and 134.4 mg. adenine N; 0.8792 gm. guanine; 0.2592 gm. adenine.
- 1.6828 gm. (231.7 mg. total N) gave 133.1 mg. guanine N and 49.32 mg. adenine N. 17.06 per cent guanine N; 5.65 per cent adenine N; purine base N = 78.70 per cent of total N.
- 1.1754 gm. (161.9 mg. total N) gave 99.19 mg. guanine N and 31.94 mg. adenine N. 18.22 per cent guanine; 5.24 per cent adenine; purine base N = 81.0 per cent of total N.
- 0.9866 gm. (135.9 mg. total N) gave 84.34 mg. guanine N and 27.18 mg. adenine N. 18.44 per cent guanine; 5.31 per cent adenine; purine base N = 82.1 per cent of total N.
- 0.5584 gm. (76.89 mg. total N) gave 59.96 mg. purine base N = 78.0 per cent of total N.
- 0.8351 gm. (115.0 mg. total N) gave 92.75 mg. purine base N = 80.7 per cent of total N.
- 0.6590 gm. (90.7 mg. total N) gave 73.86 mg. purine base N = 81.4 per cent of total N.
- 0.4791 gm. (65.97 mg. total N) gave 49.15 mg. purine base N = 74.5 per cent of total N.
- C. 1.6757 gm. (236.1 mg. total N) gave 127.4 mg. guanine N and 45.9 mg. adenine N. 16.40 per cent guanine; 5.28 per cent adenine; purine base N = 73.4 per cent of total N.
- 2.0481 gm. (288.6 mg. total N) gave 158.8 mg. guanine N and 56.3 mg. adenine N. 16.72 per cent guanine; 5.30 per cent adenine; purine base N = 74.5 per cent of total N.

A preparation of the β -protein gave 128.9 mg. guanine N and 44.4 mg. adenine N. Guanine = 0.2781 gm.; adenine = 0.0856 gm.; guanine: adenine = 3.25.

Umber's protein gave 217.1 mg. guanine N and 88.2 mg. adenine N. Guanine = 0.4683 gm.; adenine = 0.1702 gm.; guanine: adenine = 2.75.

In A₁ the loss in weight was determined by drying over P₂O₅ *in vacuo* at room temperature; after 2 weeks the weight was constant and remained unchanged for 6 months.

1.7928 gm. lost 0.2796 gm. = 15.45 per cent H₂O.

0.3678 " " 0.0571 " = 15.52 " " H₂O.

0.2926 " " 0.0456 " = 15.58 " " H₂O.

0.1840 " " 0.0281 " = 15.27 " " H₂O.

In the determination of the amounts of N, P, pentose, and Ca in the different preparations, the following values were found:

A₁. 0.1076 gm. corresponded to 14.81 cc. N/14.01 Na₂S₂O₃ solution (Kjeldahl) = 13.76 per cent N.

0.0981 gm. corresponded to 13.52 cc. N/14.01 Na₂S₂O₃ solution (Kjeldahl) = 13.78 per cent N.

0.0714 gm. corresponded to 9.83 cc. N/14.01 Na₂S₂O₃ solution (Kjeldahl) = 13.77 per cent N.

0.2891 gm. gave 0.0767 gm. Mg₂P₂O₇⁶ = 7.40 per cent P.

0.2717 " " 0.0700 " Mg₂P₂O₇⁶ = 7.18 " " P.

0.3106 " " 0.0820 " Mg₂P₂O₇⁶ = 7.36 " " P.

2.5308 gm. gave, after distillation with hydrochloric acid,⁷ 0.5797 gm. furfuralphloroglucine = 23.17 per cent pentose.

0.4624 gm. of the dried substance gave (after melting with KOH, precipitating the phosphoric acid, according to the acetate method, and the calcium as oxalate) after igniting the calcium oxalate 0.0376 gm. CaO = 5.81 per cent Ca.

0.6464 gm. of the dried substance gave, treated in the same way, 0.0523 gm. CaO = 5.78 per cent Ca.

B₁. 0.0750 gm. corresponded to 11.19 cc. N/14.01 Na₂S₂O₃ solution (Kjeldahl) = 14.92 per cent N.

0.0664 gm. corresponded to 9.91 cc. N/14.01 Na₂S₂O₃ solution (Kjeldahl) = 14.92 per cent N.

0.2810 gm. gave 0.0791 gm. Mg₂P₂O₇ (Woy) = 7.85 per cent P.

0.2747 " " 0.0769 " Mg₂P₂O₇ " = 7.80 " " P.

B₂. 0.0694 gm. corresponded to 10.24 cc. N/14.01 Na₂S₂O₃ solution (Kjeldahl) = 14.76 per cent N.

0.0843 gm. corresponded to 12.91 cc. N/14.01 Na₂S₂O₃ solution (Kjeldahl) = 15.20 per cent N

⁶ After melting with KOH and precipitating off the P, according to Woy, *Chem.-Ztg.*, 1897, xxi, 442, 469.

⁷ Tollens, B., in Abderhalden E., *Handbuch der biochemischen Arbeitsmethoden*, Berlin and Vienna, 1910, ii, 130.

- 0.0876 gm. corresponded to 13.09 cc. N/14.01 $\text{Na}_2\text{S}_2\text{O}_3$ solution (Kjeldahl) = 14.94 per cent N.
- 0.2382 gm. gave 0.0676 gm. $\text{Mg}_2\text{P}_2\text{O}_7$ (Woy) = 7.91 per cent P.
- 0.2771 " " 0.0792 " $\text{Mg}_2\text{P}_2\text{O}_7$ " = 7.97 " " P.
- 1.2080 gm. gave after distillation with hydrochloric acid, 0.3020 gm. furfurophloroglucine = 25.50 per cent pentose.
- C. 0.0892 gm. corresponded to 12.45 cc. N/14.01 $\text{Na}_2\text{S}_2\text{O}_3$ solution (Kjeldahl) = 13.96 per cent N.
- 0.0711 gm. corresponded to 10.13 cc N/14.01 $\text{Na}_2\text{S}_2\text{O}_3$ solution (Kjeldahl) = 14.25 per cent N.
- 0.2270 gm. gave 28.0 cc. N (at 739.0 mm. Hg and 20°C.) (Dumas) = 13.97 per cent N.
- 0.2998 gm. gave 37.1 cc. N (at 750.0 mm. Hg and 21°C.) (Dumas) = 14.18 per cent N.
- 0.2455 gm. gave 0.0675 gm. $\text{Mg}_2\text{P}_2\text{O}_7$ (Woy) = 7.66 per cent P.
- 0.3672 " " 0.0979 " $\text{Mg}_2\text{P}_2\text{O}_7$ " = 7.43 " " P.
- 0.3302 " " 0.0888 " $\text{Mg}_2\text{P}_2\text{O}_7$ " = 7.50 " " P.
- 1.1357 gm. gave after distillation with hydrochloric acid, 0.2867 gm. furfurophloroglucine = 25.76 per cent pentose.
- The results are summarized in Tables III and IV.

Before discussing the results, I would call attention to the fact that it is impossible to give even a probable formula for the analyzed nucleic acid. Nevertheless I venture to suggest a formula, only for the purpose of pointing out one possibility of composition and structure which approximately corresponds to the values found.

The relation between nitrogen and phosphorus was constant in the different preparations, a fact which strongly argues for a unit substance. As already mentioned the ratio $\frac{\text{N}}{\text{P}} = 1.89$ does not correspond either with that of a common tetranucleotide (1.69) or with that of a purine mononucleotide (2.26), while for a nucleic acid with 25 atoms of N and 6 atoms of P the ratio would be 1.88. The values found for the ratio $\frac{\text{guanine}}{\text{adenine}}$ argue for the probability that 1 molecule of the analyzed nucleic acid contains 3 molecules of guanine and 1 molecule of adenine (calculated $\frac{3 \text{ mols guanine}}{1 \text{ mol adenine}} = 3.36$).

About 75 per cent of the total amount of nitrogen was determined as purine base nitrogen. 3 molecules of guanine and 1

TABLE III.

Preparation.	N	P	H ₂ O	Ca deter- mined on dried sub- stance.	Gua- nine.	Ad- nine.	Purine base N in per cent of the total amount of N	Pen- tose.
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	
A ₁	13.76	7.40	15.45	5.78	17.06	5.65	71.0; 78.7	
	13.78	7.18	15.52		18.22	5.24	81.0; 82.1	
	13.77	7.36	15.58	5.81	18.44	5.31	78.0; 80.7	
			15.27				81.4; 74.5	
Average	13.77	7.31	15.46	5.80	17.91	5.40	78.4	23.17
B ₁	14.92	7.85						
	14.92	7.80						
Average	14.92	7.83						
B ₂	14.76	7.91						
	15.20	7.97						
	14.94							
Average	14.96	7.94			12.09	4.04		25.50
C	13.96	7.66			16.40	5.28	73.4	
	14.25	7.43						
	13.97	7.50			16.72	5.30	74.5	
	14.18							
Average	14.09	7.53			17.56	5.29	74.0	25.76

TABLE IV.

Preparation.	$\frac{N}{P}$	$\frac{\text{Guanine}}{\text{Adenine}}$	$\frac{\text{Pentose}}{N}$
A ₁		3.02	
		3.48	
		3.47	
	1.88	3.32	1.68
B ₁	1.90		
B ₂	1.88	2.99	1.70
C		3.11	
		3.15	
	1.87	3.13	1.83
Average.....	1.89	3.15	1.74

molecule of adenine give together 20 atoms of N. With the assumption of 25 atoms of N in the examined nucleic acid, 5 atoms would stand in other groups. As cytosine and thymine were found, there is the possibility that the remaining 5 N atoms (20 per cent of the total nitrogen) could be divided between 1 molecule of thymine and 1 molecule of cytosine. The values thus far discussed could correspond to a compound of 2 molecules of guanylic acid and 1 molecule of tetranucleotide. With the assumption of the possible formulation for the "ideal" tetranucleotide, proposed by Steudel,² and more accurately by Levene and by Feulgen,³ the following structure could be assumed.

TABLE V.

	Calculated.		On A ₁ , found values, counted to dry substance. Ca directly determined on dried substance
	Formula I.	Formula II	
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
N	16.63	16.57	16.29
P	8.84	8.81	8.65
Ca	5.71	5.69	5.80
<u>Pentose</u> N	0.857	1.71	1.68

2 molecules of guanylic acid united with 1 molecule of tetranucleotide by ester linkings between phosphoric acid and carbohydrate (Formula I), or a nucleic acid composed as the above mentioned, only with the difference that all the purine base nucleotides contain, as carbohydrate pentose and the pyrimidine base nucleotides, hexose (Formula II).

Values can accordingly be calculated for the 6-basic Ca salts as given in Table V.

The calculation is made with the following formulas: 6 mols phosphoric acid + $\left\{ \begin{array}{l} 4 \text{ mols (I)} \\ 2 \text{ mols (II)} \end{array} \right.$ hexose ($C_6H_{10}O_4$) + $\left\{ \begin{array}{l} 2 \text{ mols (I)} \\ 4 \text{ mols (II)} \end{array} \right.$ pentose ($C_5H_{10}O_5$) + 3 mols guanine + 1 mol adenine + 1 mol thymine + 1 mol cytosine + 3 atoms Ca. From this 17 mols water and 6 atoms hydrogen were deducted for the linkings. The calculated molecular weights were 2106.16 (I) and 2114.16 (II).

³ Feulgen, R., *Z. physiol. Chem.*, 1918, ci, 288.

All the values found accord with both Formula I and Formula II except the values for the pentose, which explicitly speak in favor of Formula II. The method of furfural distillation for the determination of pentose is, however, quite conventional, and furthermore different amounts of furfural can be generated from hexose⁹ during the distillation.

Once more, I want to point out that I am quite conscious of the fact that the above speculation about the formulas lacks adequate experimental basis.

As mentioned several times before, Preparation C gives a flocky precipitate when it is warmed in alkaline solution and neutralized with acetic acid. This precipitate was at first noted as a dense opalescence, and then became at a slightly alkaline reaction a gelatinous porridge. After standing for 24 hours in the cold the precipitate was filtered, washed several times with cold water, dissolved in a solution of sodium hydroxide, and the solution neutralized with acetic acid. After 24 hours it was filtered and washed with cold water, then dissolved in water, precipitated with two volumes of alcohol, and dried with alcohol and ether.

In this preparation (dried in the air) the N and P analyses were made.

0.0492 gm. corresponded to 6.96 cc. N/14.01 $\text{Na}_2\text{S}_2\text{O}_3$ solution (Kjeldahl) = 14.15 per cent N.

0.0586 gm. corresponded to 8.41 cc. N/14.01 $\text{Na}_2\text{S}_2\text{O}_3$ solution (Kjeldahl) = 14.35 per cent N.

0.2647 gm. gave 0.0626 gm. $\text{Mg}_2\text{P}_2\text{O}_7$ (Woy) = 6.59 per cent P.

0.4568 " " 0.1087 " $\text{Mg}_2\text{P}_2\text{O}_7$ " = 6.63 " " P.

$\frac{\text{N}}{\text{P}} = \frac{14.25}{6.61} = 2.16$. For guanylic acid calculated to 2.26.

0.5 gm. of the preparation was decomposed with nitric acid according to Steudel. Guanine could be precipitated with ammonia in ample quantities. In the ammoniacal filtrate only traces of purine bases remained. The substance is apparently composed of an alkali salt of guanylic acid. The preparation was easily soluble in water, and the aqueous solution gave with a small amount of sodium acetate a gelatinous precipitate. By adding acetic acid it was turned into a soft jelly. With calcium chloride the aqueous solution gave at once a solid jelly.

⁹ Steudel, R., *Z. physiol. Chem.*, 1908, lvi, 212.

These circumstances accord with the observations of Feulgen¹⁰ on the solubility of the alkali salts of guanylic acid. According to this investigator the neutral alkali salt of guanylic acid is easily soluble in water and is not precipitated by acetic acid but transformed into the gelatinous acid salt. Furthermore the alkali salts of guanylic acid are dissolved with great difficulty in a solution of sodium acetate, a fact on which Feulgen has based a method for isolating guanylic acid. The low solubility in sodium acetate is without doubt the reason why the alkali salt of the guanylic acid was precipitated by neutralizing with acetic acid the alkaline hydrolyzed solution.

The first filtrate from the alkali salt of guanylic acid still contained guanylic acid, which could be (according to Feulgen) precipitated with sodium acetate.

The results of the experiments on the nucleic acids, which remained in the solution, will be reported in a second communication.

The reaction on warming with 1 per cent solution of sodium hydroxide was followed by observations of the alterations in the hydrogen ion concentration, resistance, and freezing point.

In a 4 per cent solution of Preparation C in a 1 per cent solution of sodium hydroxide [H], resistance,¹¹ and Δ^{11} were determined before and after warming. The solutions were prepared just before the experiments and then, during the experiments, were protected by tubes of soda-lime from the carbonic acid in the air.

In each experiment 25 cc. were warmed during 10 minutes one or several times in a boiling water bath. The solution remained absolutely clear even after warming 30 minutes. For the determination of [H] and resistance the same solution was used. The transfer of the solution from the heating vessel to the measuring vessel for the electric resistance, and from this to the hydrogen electrode, was made with protection against the carbonic acid of the air. The determination of the freezing point could not be made in a solution of 1 per cent sodium hydroxide, because precipitation occurred at the low temperature in spite of the alkaline

¹⁰ Feulgen, R., *Z. physiol. Chem.*, 1919, cvi, 249.

¹¹ The directly found values of resistance in ohms and the freezing point in degrees, without consideration of the resistance capacity of the measuring vessel or of the zero correction of the thermometer.

reaction. These determinations were accordingly made with 4 per cent solution of Preparation C in a solution of 2 per cent sodium hydroxide. During the heating, nevertheless, a very small dark-colored precipitate formed, which, it may be, makes the results of these determinations somewhat uncertain.

The values for resistance and Δ are the directly observed values without any consideration of the calibration of the instruments, as only the relative values here are of interest (Table VI).

TABLE VI.

Preparation C, a 4 per cent* solution in a solution of 1 per cent NaOH.	Resistance.	[H] normality.	Δ †
	<i>ohms</i>		°C
Before heating.....	173	8.20 ⁻¹⁴	2.468
After standing 24 hrs. at 0°.....	173	8.20 ⁻¹⁴	
“ warming 10 min.....	217	1.81 ⁻¹³	2.469
“ “ 20 “	217.9	2.21 ⁻¹³	2.460
“ “ 30 “	220	2.29 ⁻¹³	

* As about 0.001 molecular, calculated as nucleic acid.

† 2 per cent solution of NaOH.

TABLE VII.

Alkali salt of guanylic acid, 4 per cent solution in 1 per cent solution of NaOH.	Resistance.	[H]
	<i>ohms</i>	
Before heating.....	147	1.31 ⁻¹³
After “ 10 min.....	149	1.31 ⁻¹³

Different experiments, even with Preparation B₂, were made with quite the same results.

The alkali salt of guanylic acid (compare above) was dissolved in a solution of 1 per cent sodium hydroxide and resistance and [H] were determined before and after warming (Table VII).

The experiments (Table VI) show that [H] was increased through heating of the alkaline solution, which is the same as a disappearance of OH ions. The increase in the resistance may thus be ascribed to the disappearance of mobile OH ions. The freezing point was not altered by heating, a fact which forces the conclusion that the absolute quantity of some other kind of

ions has increased. All the found values for resistance, $[H]$, and Δ showed thus in good agreement that an hydrolysis had taken place, whereby 2 or more molecules had been separated from each other.

By repeated experiments I have convinced myself that no phosphoric acid was detached during the heating with sodium hydroxide. On the other hand it was easy to show that by heating a solution of C in water ample quantities of phosphoric acid were detached, and that this cleavage could be prevented by small amounts of sodium hydroxide.

The cleavage of phosphoric acid from nucleic acids by heating their alkaline solutions proceeds gradually, as Feulgen¹² has shown. As is shown in Table VI, the hydrolysis, however, was finished after 10 minutes (probably much earlier). The same is shown by Table VII. Here the alkali salt of guanylic acid, which had been isolated from the hydrolyzed solution, was heated in a solution of 1 per cent sodium hydroxide, without any alteration of the hydrogen ion concentration, or of the electrical resistance.

It is probable that, through the hydrolysis in alkaline solution, ester linkings between two or more nucleic acids (of which one is guanylic acid) were dissolved.

The substance, which was prepared by Feulgen¹ by enzymatic digestion of β -protein from pancreas, and by him called "Guanylnucleinsäure" is without any doubt closely related to the one described by me. Feulgen found the same cleavage products for his nucleic acid that I have found. After hydrolysis it was possible for him to precipitate an alkali salt of guanylic acid with sodium acetate. From the amounts of guanylic acid found he calculated that 1 molecule of guanylic acid is united with 1 molecule of tetranucleotide. According to my results, probably at least 2 molecules of guanylic acid are to be found in every molecule of my nucleic acid. Feulgen's nucleic acid was dextrorotatory, which was also the case with my nucleic acid.

Of greater interest than the settling of the quantitative composition of these complicated substances seems to me to be the proof of the occurrence of genuine compounds, capable of being hydrolytically split, between "single" and "compound" nucleic acids.

¹² Feulgen, R., *Z. physiol. Chem.*, 1914, xci, 165.

I suggest "conjugated nucleic acids" as a name for such compounds. Whether "conjugated nucleic acids" occur in the organisms as such, or whether they are only artificial products, is a question outside the province of this paper.

The experiments are being continued.

WATER-SOLUBLE VITAMINES.

I. ARE THE ANTINEURITIC AND THE GROWTH-PROMOTING WATER-SOLUBLE B VITAMINES THE SAME?

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The object of the present paper is to present data which we believe indicate that a more definite distinction should be made, for the present at least, between the antineuritic and certain of the other water-soluble vitamins, particularly those that relate to the growth stimuli.

Since making our preliminary reports (1, 2) on this subject, Mitchell (3) has presented an excellent review of the literature, and we will limit ourselves to a brief summary of the published work that bears directly upon the particular phase of the problem as we have approached it; namely, the stability of the water-soluble vitamins to heat.

We have, therefore, made a compilation of the available data on the basis of the particular biological test for which the trials were planned with only a secondary consideration of the descriptive names associated with the vitamins employed.

In comparing the data in Tables I and II, it should be borne in mind, as Chick and Hume (4) have brought out, that the amount of ration consumed may carry an excess of the vitamin beyond the minimum requirements, and, if so, a partial destruction of the vitamin by heat, alkali, or other causes might not necessarily become evident in the biological tests.

Comparing the results in the two tables, they tend to indicate that the antineuritic and the growth-promoting vitamins, as measured by polyneuritic pigeons and young rats respectively, were fairly stable at temperatures around 100–105°C. At higher temperatures, the antineuritic vitamin seemed to be less stable

TABLE I.
*Polynneuritis (Antineuritic Vitamine).**

Series.	Temperature and time of heating.	Destruction.	Reference.
Section I. Fowl: pigeon, chicken, and duck.			
A	100°C., moist heat.		
1a†	Egg yolk, 4 min.	None apparent.	Cooper (5).
2a	" " in presence of dilute alkali.	Total.	Steenbock (6).
3b†	Buffalo meat, several days.	"	Grijns (7).
4b	Beef, 30 min.	None apparent.	Holst (8).
5a	Yeast extract, 1 hr.	Slight.	Chick and Hume (9).
6a	Wheat embryo, 1 hr.	Very slight.	Chick and Hume (9, 10).
7b	Unmilled rice, 3 hrs.	None apparent.	Eykman (11).
B	110°, autoclave, 30 min.		
8b	Beef.	Appreciable.	Holst (8).
C	113°, autoclave, 1 hr.		
9a	Wheat embryo (102-107° for 40 min.).‡	Slight.	Chick and Hume (10).
D	115°, autoclave, 2 hrs.		
10b	Unmilled rice, millet, oats, rye, barley.	Total.	Eykman (11).
E	120°, 15 pounds pressure, 30 min.		
11b	Beef, eggs.	Marked.	Vedder (12).
12b	Dried peas, unhulled barley.	None apparent.	Holst (8).
F	120°, 15 pounds pressure, 1 hr.		
13b	Beef.	Total.	"
G	120°, 15 pounds pressure, 1½ hrs.		
14b	Unmilled rice.	"	Weil, Mouriquand, and Michel (13).
15b	Barley.	"	Weil and Mouriquand (14).

TABLE I—*Concluded.*

Series.	Temperature and time of heating.	Destruction.	Reference.
Section I. Fowl: pigeon, chicken, and duck— <i>Concluded.</i>			
H	120°, 15 pounds pressure, 2 hrs.		
16b	Unmilled rice, Katjidgo beans, buffalo meat.	Total.	Grijns (7), Eykman (11).
17b	Horse meat.	None apparent.	Eykman (11).
18b	Rye, unmilled rice, millet, oats, barley.	Total.	Holst (8).
I	122°, autoclave, 1 hr.		
19a	Yeast extract and wheat embryo, (110–117° for 40 min.).†	Appreciable.	Chick and Hume (9, 10).
J	122°, autoclave, 2½ hrs.		
20a	Yeast extract and wheat embryo (118–124° for 2 hrs.)‡	Very marked.	“ “
K	125°, autoclave, 2 hrs.		
21b	Unmilled rice and millet.	Total.	Eykman (11).
L	135°, autoclave, 2 hrs.		
22b	Unmilled rice, rye, millet, oats, barley.	“	Holst (8).
Section II. Dogs.			
M	120–130°, autoclave, 1 to 3 hrs.		
23b	Horse meat.	Total.	Schaumann (15).
24b	Lean beef in presence of 10 per cent Na ₂ CO ₃ .	“	Voegtlin and Lake (16).
Section III. Cats.			
N	120°, 15 pounds pressure, 3 hrs.		
25b	Lean beef.	Appreciable.	Voegtlin and Lake (16).
26b	“ “ in presence of 10 per cent Na ₂ CO ₃ .	Total.	“ “

* Designated by some as water-soluble B, growth-promoting factor, neuritic-preventing vitamine, and antiberi-beri vitamine.

† a, tested curatively by giving it to polyneuritic fowl; b, tested prophylactically by feeding normal fowl.

‡ Temperature of the substance itself and length of time it remained at this point.

TABLE II.
Growth-Promoting Vitamine (Water-Soluble B).*

Series.	Temperature and time of heating.	Destruction.	Reference.
Section I. Rats.			
A	90-100°C., dry heat, several hrs.		
1	Liver, heart, kidney, brain.	None apparent.	Osborne and Mendel (17).
B	100°, moist heat.		
2	Protein-free milk, 2 min.	None apparent.	Osborne and Mendel (18).
3	Milk whey, 6 hrs.	" "	McCollum and Davis (19).
4	Extract yeast, 30 min.	" "	Drummond (20).
5	Extract wheat embryo, in presence of 0.28 per cent NaOH, 1 hr.	Total.	McCollum and Simmonds (21).
6	Extract yeast, in presence of 5 per cent NaOH, 5 hrs.	Marked.	Drummond (20).
7	Soy beans, navy beans, cabbage, 40 to 120 min.	None apparent.	Daniels and McClurg (22).
8	Soy beans (120 min.), navy beans (90 min.), cabbage (45 min.), in presence of 5 per cent NaHCO ₃ .	" "	" "
9	Carrots.†	" "	Denton and Kohman (23).
10	Yeast, 0.1 N NaOH for 21.5 hrs. in cold. 2 hrs. heating.	" "	Osborne, Wakeman, and Ferry (24).
C	105°, dry heat, several hrs.		
11	Meat powder (lean beef).	" "	Osborne and Mendel (25).
12	Beef extract.	" "	" "
13	Compressed yeast.	" "	Hawk, Fishback, and Bergeim (26).

* Designated by some as water-soluble B, antineuritic vitamine, and water-soluble growth-promoting accessory factor.

† Placed in cans, then immersed in water, and heated at 100° for 2 hrs.

TABLE II—*Continued.*

Series.	Temperature and time of heating.	Destruction.	Reference.
Section I. Rats— <i>Continued.</i>			
D	120°, 15 pounds pressure, 20 min.		
14	Navy beans, cabbage.	None apparent.	Daniels and McClurg (22).
15	Extract, navy beans.	" "	" "
E	120°, 15 pounds pressure, 30 min.		
16	Extract yeast.	Marked.	Drummond (20).
17	Soy bean flour.	None apparent.	Cohen and Mendel (27).
18	Extract, navy and soy beans, in presence of 0.1 N NaOH.	" "	Daniels and McClurg (22).
F	120°, 15 pounds pressure, 40 min.		
19	Navy beans.	None apparent.	McCollum and Simmonds (21).
20	Soy beans.	" "	Daniels and McClurg (22).
21	Extract, soy beans.	" "	" "
G	120°, 15 pounds pressure, 1 hr.		
22	Wheat embryo, milk whey.	" "	McCollum and Davis (19).
23	Extract, navy bean, in presence of 0.1 N NaOH.	" "	Daniels and McClurg (22).
H	120°, 15 pounds pressure, 1½ hrs.		
24	Navy bean.	" "	McCollum, Simmonds, and Pitz (28).

TABLE II—*Concluded.*

Series.	Temperature and time of heating.	Destruction	Reference
Section I. Rats— <i>Concluded.</i>			
I 25	120°, 15 pounds pressure, 3 hrs. Lean beef, in presence of 10 per cent Na_2CO_3 .	None apparent.	Voegtlin and Lake (16).
Section II. Yeast cell.			
J 26	120°, 15 pounds pressure, 30 min. Yeast extract.	Slight.	Williams (29).

to heat and alkali than the rat growth-promoting vitamine, as shown in the case of wheat embryo (Table I, Series I, and Table II, Series G) and in lean beef (Table I, Series M and N, and Table II, Series I). The fact that no data were given as to the amount of food consumed by the rats, dogs, and cats in Voegtlin and Lake's work (16) is unfortunate as one might then have been able to evaluate their data from the standpoints under consideration here.

EXPERIMENTAL.

The plan of the series of trials reported was to use the *same* source of water-soluble vitamins for the studies on polyneuritis in pigeons and the rate of growth in young rats.

The basal food employed was unmilled rice. This furnished the only source of the water-soluble antineuritic and growth-promoting vitamins. In the case of the pigeons, the unground rice constituted the sole food. Gravel was offered once a week. With the rats, the ground rice was so supplemented with lactalbumin, salt mixture (21), butter fat, and lard that it formed a balanced ration for growth. The fundamental difference in the diets of the respective groups of pigeons and rats was in the use of unmilled rice that was unheated for the controls and of rices that were heated at different temperatures.

The heating of the rice was carried out as follows: in the air oven at 120°C. for 2 hours, after the temperature reached this point; and in the autoclave at 120° and 15 pounds pressure for

1, 2, and 6 hours, respectively—making in all four different samples. In some of the trials the pigeons were allowed to eat their food at will, others were force-fed as soon as they began to refuse their food. The pigeons were put in cages in groups of seven each. Each rat was kept in a separate compartment. The food intake of the rats was determined directly, that for the pigeons had to be calculated from the total consumption of rice for the entire group.

DISCUSSION.

Part I. Influence of Degree of Heating on the Antineuritic Vitamine, Using Pigeons.

The results presented in Charts 1 and 2 show the relative rate at which pigeons come down with polyneuritis when fed *ad libitum* unheated and heated unmilled rice. From these it is evident that some decided change took place in the rices that were subjected to the longer periods of heating. Naturally the first question that arises is in regard to the amount of the food consumed by the different lots. A fair idea of this is given in Table III.

The values are somewhat approximate due to the fact that the pigeons were fed in groups and also that they scattered some food. The refused food in the cups and on the metal floor of the cages was collected and subtracted from the total amounts offered.

TABLE III.

Food Consumed by Pigeons Fed ad Libitum.

(Gm. of food per day per 100 gm. of body weight.)

Period.	Unheated rice.	Rice, 1 hr. in autoclave at 120°.	Rice, 2 hrs. in autoclave at 120°.	Rice, 6 hrs. in autoclave at 120°.	Rice, 2 hrs. dry heat at 120°.
	gm.	gm.	gm.	gm.	gm.
1st week.....	7.6	8.1	8.0	7.2	8 8
2nd "	8.0	8.6	6.3	5.8	6 3
4th "	8.2	9.0	4.9	4.8	6 5
Average.....	8.0	8.6	6.4	5.9	6.7

The results indicate that the loss in weight varied inversely with the amount of rice eaten.

The fact that the food intake varied in this manner suggested that two or three factors might be involved in the causation of the onset of polyneuritis. The excessive heating might have destroyed the antineuritic vitamine; it might have produced certain toxic substances which prevented the vitamine from being potent; or it might have altered the physical condition of the rice making it harder and less easily digestible.

In view of these possibilities, it was decided to force-feed pigeons and compare the effects produced with those fed *ad libitum*. These curves are presented in Chart 3. In the main the results obtained were identical with what was found when the pigeons were fed *ad libitum*.

The question of the formation of toxic substances is still unanswered. In view of this, it was decided to carry out a series of experiments by force-feeding pigeons on unheated *milled* rice and then treating them with small quantities of an extract of autolyzed yeast which had been heated in the same manner as the natural or unmilled rices in Chart 3. In this way, it would be possible to eliminate any resultant conditions produced in the unmilled rice during the heating, such as undue hardness, peculiar aroma, etc. Since the amount of the vitamine extract given in this treatment was relatively small, being 0.19 gm. daily, it would seem that the toxic effect, if any, that could have been caused by adding this material to the rice diet was too insignificant to be considered seriously. The results are given in the first half of Chart 9.

In order to test this point of toxicity further, curative trials were made with extracts containing the antineuritic vitamine both before and after heating. Besides, vitamine extracts were treated with fullers' earth according to the method of Seidell (30) and the activated silicate was used. The results are presented in Table IV. These results together with those in Chart 9 show conclusively, even if reasonable allowances are made for the indefiniteness that sometimes appears in cases of polyneuritic pigeons, that toxicity was apparently a minor factor and that the antineuritic vitamine was totally destroyed by heating for 2 and 6 hours in the autoclave at 120° and 15 pounds pressure.

TABLE IV.

Treatment of Typical Polyneuritic Pigeons with Heated and Unheated Vitamine Preparations.

Bird No.	Treatment.	Response to treatment.
331	0.3 gm. unheated yeast extract.	Good recovery.
326	0.3 " " " "	" "
338	0.1 " " " "	Improved.
300	0.5 " 6 hrs. autoclaved yeast extract in a.m.	No better. Given a second treatment in p.m.
	0.5 " 6 hrs. autoclaved yeast extract in p.m.	Found dead next morning.
293	0.5 " 6 hrs. autoclaved yeast extract in a.m.	No better. Given a second treatment in p.m.
	0.5 " 2 hrs. autoclaved yeast extract in p.m.	Found dead next morning.
303	0.5 " 6 hrs. autoclaved yeast extract.	" " " "
394	0.5 " 2 hrs. autoclaved yeast extract.	" " " "
332	0.5 " 2 hrs. autoclaved yeast extract.	" " " "
405	0.5 " 2 hrs. yeast extract, 1st day.	No better. Treated following morning. Good recovery.
	0.5 " unheated yeast extract, 2nd day.	
414	0.6 " unheated activated protein-free milk.	Very good recovery.
436	0.6 " unheated activated protein-free milk.	" " "
433	0.6 " activated 6 hrs. autoclaved yeast extract.	No better. Treated second day.
	0.6 " activated unheated yeast extract, 2nd day.	Very good recovery.
422	0.6 " activated unheated yeast extract.	Good recovery.
404	0.6 " 6 hrs. autoclaved activated protein-free milk.	Found dead next morning.
432	0.6 " 6 hrs. autoclaved activated protein-free milk, 1st day.	No better. Treated second day.
	0.6 " unheated activated protein-free milk, 2nd day.	Very good recovery.

Part II. Influence of Degree of Heating on the Water-Soluble B Growth-Promoting Vitamine, in Rats.

Four groups of young rats were so fed that a comparison of the rate of growth of each would indicate the relative degree of destruction of this water-soluble vitamine by heating the rice.

The ration for the control group was made up as follows:

	<i>per cent</i>
Period 1. Unmilled rice, unheated.....	64.0
Lactalbumin.....	6.0
Butter fat.....	18.0
Lard.....	10.0
Salt mixture.....	2.0
Period 2. Unmilled rice, unheated.....	89.7
Lactalbumin.....	3.3
Butter fat.....	5.0
Salt mixture.....	2.0

Equivalent percentages of rice were used throughout, calculated on the dry basis, and then the necessary amount of water was added to bring all the rations to the same moisture content. We recognize that this method of adjusting the rations did not necessarily allow for the variations in palatability that might have been brought about during the heating of the rices. The food intake of each rat should, however, assist in interpreting the results from this standpoint.

The data are presented in Charts 4, 5, 6, and 7. When the individuals in the groups are compared, the greatest variation is found in the case of the 6 hours autoclaved rice (Chart 7).

In Chart 8 the average results for each group are given. These average group curves indicate that the heating processes apparently had some detrimental effect during the 6 hours in the autoclave at 120° and but very slight, if any, effect during 2 hours at 120° either in the oven or autoclave. A study of these data in connection with the food intake and the percentage gain per gm. of food consumed (Tables V and VI) will assist further in evaluating the rations.

In Table V, the amount of food consumed per day per rat is given. The differences in food intake between Groups 40, 50, and 60 were no greater than the differences between the values for the individual rats in the respective groups. In the case of

Group 70, however, the rats ate less of the ration, except Rat 75 which consumed as much as some of the animals in the other groups. The gains in weight of this rat compared favorably with those in the other groups having an equivalent food intake.

TABLE V.
Food Consumed.

Group No.	Ration and rat No.	Food consumed per day per rat.				
		Rat 1.	Rat 2.	Rat 3.	Rat 4.	Group average.
Period 1 (75 days).						
40	Unheated rice. Rats 41, 42, 43.	gm. 5.9	gm. 5.6	gm. 4.2		gm. 5.2
50	2 hrs. dry heat 120°. Rats 52, 54, 56.	4.9	6.5	5.9		5.8
60	2 hrs. autoclave 120°. Rats 62, 63, 64, 66.	5.6	4.5	4.2	5.2	4.9
70	6 hrs. autoclave 120°. Rats 71, 72, 73, 75.	3.3	2.6	3.1	4.3	3.3
Period 2 (50 days).						
40	Unheated rice. Rats 41, 42, 43.	10.8	10.1	11.5		10.8
50	2 hrs. dry heat 120°. Rats 52, 54, 56.	8.2	10.1	11.3		9.9
60	2 hrs. autoclave 120°. Rats 62, 63, 64, 66.	7.0	8.1	7.8	9.0	8.0
70	6 hrs. autoclave 120°. Rats 71, 72, 73, 75.	4.7	3.3	3.6	7.5	4.8
Periods 1 and 2 (125 days).						
40	Unheated rice. Rats 41, 42, 43.	7.8	7.4	7.1		7.4
50	2 hrs. dry heat 120°. Rats 52, 54, 56.	6.2	7.9	8.0		7.4
60	2 hrs. autoclave 120°. Rats 62, 63, 64, 66.	6.1	5.9	5.6	6.8	6.1
70	6 hrs. autoclave 120°. Rats 71, 72, 73, 75.	3.9	3.2	3.7	5.8	4.1
Period 3 (21 days).						
70	Unheated rice (same as No. 40). Rats 71, 72, 73, 75.	9.0	5.5	7.7	9.7	8.0

TABLE VI
Gain per Gm. of Food Consumed.

Group No.	Ration and rat No.	Gain per gm. of food.				
		Rat 1.	Rat 2.	Rat 3.	Rat 4.	Group average.
Period 1 (75 days).						
40	Unheated rice. Rats 41, 42, 43.	20.3	20.0	17.5		19.3
50	2 hrs. dry heat 120°. Rats 52, 54, 56.	20.9	17.7	22.2		20.3
60	2 hrs. autoclave 120°. Rats 62, 63, 64, 66.	18.2	20.0	14.5	16.1	17.2
70	6 hrs. autoclave 120°. Rats 71, 72, 73, 75.	15.1	(6.9)	13.0	16.6	14.9
Period 2 (50 days).						
40	Unheated rice. Rats 41, 42, 43.	8.8	7.7	11.1		9.2
50	2 hrs. dry heat 120°. Rats 52, 54, 56.	8.3	4.0	11.4		7.9
60	2 hrs. autoclave 120°. Rats 62, 63, 64, 66.	6.7	7.1	12.6	12.7	9.8
70	6 hrs. autoclave 120°. Rats 71, 72, 73, 75.	10.6	(3.3)	3.5	11.5	8.5
Periods 1 and 2 (125 days).						
40	Unheated rice. Rats 41, 42, 43.	14.5	13.8	14.3		14.2
50	2 hrs. dry heat 120°. Rats 52, 54, 56.	14.6	10.8	16.8		14.1
60	2 hrs. autoclave 120°. Rats 62, 63, 64, 66.	12.4	13.5	13.5	14.4	13.4
70	6 hrs. autoclave 120°. Rats 71, 72, 73, 75.	12.5	(5.1)	8.2	14.0	11.6
Period 3 (21 days).						
70	Unheated rice (same as No. 40). Rats 71, 72, 73, 75.	19.0	(19.8)	18.0	24.1	20.4

If the growth-promoting water-soluble vitamin had been destroyed, the rate of growth for Rat 75 would have been much less. We are confronted, therefore, with the question of the palatability of the ration and as to what the other rats in the group would have gained if they had eaten as much food. This

point is further evidenced in Period 3 where all the rats ate more and made better gains than in Periods 1 and 2. Osborne and Mendel (31) found similar conditions in palatability in the case of soy bean.

When the rations (Table VI) on the basis of the gain made per gm. of food consumed are compared, it is evident that the diets for Groups 40, 50, and 60 were all practically of equal value. The data for Group 70, Period 1, compare favorably with the lower values for these groups. In Period 2, two of the rats did very well while the other two did very poorly. For the entire time, Rats 71 and 75 were able to utilize their food to as much advantage as the rats in the other three groups, showing that this ration was as economical as the others.

It is evident from Period 3 that all the rats in this group were capable of making good gains. Therefore, if their food consumption in Periods 1 and 2 had been equal to that of the rats in Group 40 and they had maintained the same degree of utilization of their food that they did in the test trial, the gains would have been larger than any of the other groups.

As another means of determining the effect of heat on the water-soluble growth-promoting vitamine, some rats were placed on a ration that lacked this vitamine and when they showed definite signs of retardation in growth 1 per cent of an extract of brewer's yeast, after being heated in the autoclave for 6 hours at 120°, was added. The diet was made up as follows:

	<i>per cent</i>
Lactalbumin.....	11.3
Starch.....	32.7
Lactose (purified).....	24.6
Salt mixture.....	3.4
Butter fat.....	13.0
Lard.....	15.0

The curves are given in the second half of Chart 9.

SUMMARY.

In the foregoing discussion we have shown by comparing the antineuritic (pigeon) and the water-soluble B growth-promoting (rat) vitamins that in the former case the vitamine was altered

by heating the food or extracts containing it to certain temperatures while the other vitamine, obtained from the same food and extracts, apparently remained potent under the same conditions of heating. This is perhaps illustrated most definitely in Chart 9 where pigeons came down with polyneuritis on the one hand and young rats grew on the other.

The authors would call attention to the fact that the minimum vitamine requirement of the rats may have been lower per gm. of body weight than that of the pigeons. This latter point was intended to be covered in part when the amount of unmilled rice in the rat rations was increased from 64.0 to 89.7 per cent. For, first, if the heated rices were toxic the rate of growth would be definitely lowered by feeding larger amounts of rice, and, second, if the supply of the growth-promoting vitamine was sufficiently low in the 64.0 per cent ration a slight or partial destruction of the vitamine by heat would be apparent. And upon increasing the amount of rice, the quantity of vitamine would be increased and there would then be an added increment of growth.

The fact that the direction of the curves was not altered to any appreciable extent when this change was made suggests that the heated rices were not toxic, and, since the amount of water-soluble growth-promoting vitamine in the 64.0 per cent ration was apparently above the minimum requirements, these data are none too definite as to a partial destruction of the vitamine. However, it would appear if the antineuritic vitamine was the same as the water-soluble B that in the treatment of pigeons with increasing doses of heated extracts and in the force-feeding of them with the heated rices there should have been some response if the vitamine was but slightly or partially destroyed. In order to answer this question definitely, it will be necessary to measure quantitatively the amount of vitamine consumed.

CONCLUSIONS.

1. The antineuritic vitamine (pigeons) in unmilled rice is stable to heat at 120°C. and 15 pounds pressure for 1 hour. It is partially altered by heating in the air oven at 120° for 2 hours, and totally destroyed at 120° and 15 pounds pressure in 2 and 6 hours. The vitamine in extracts is more easily altered by heat.

2. The water-soluble B vitamine (rats) in unmilled rice appears to be stable to heat at these same temperatures, that is, it is not distinctly or totally broken down. Whether this vitamine was slightly destroyed could not be definitely ascertained due to the lack of quantitative methods.

3. These findings suggest tentatively, at least, that the anti-neuritic (pigeons) and the water-soluble B (rats) vitamines are not the same, and that it would be better to consider them as being different until there is further proof to the contrary.

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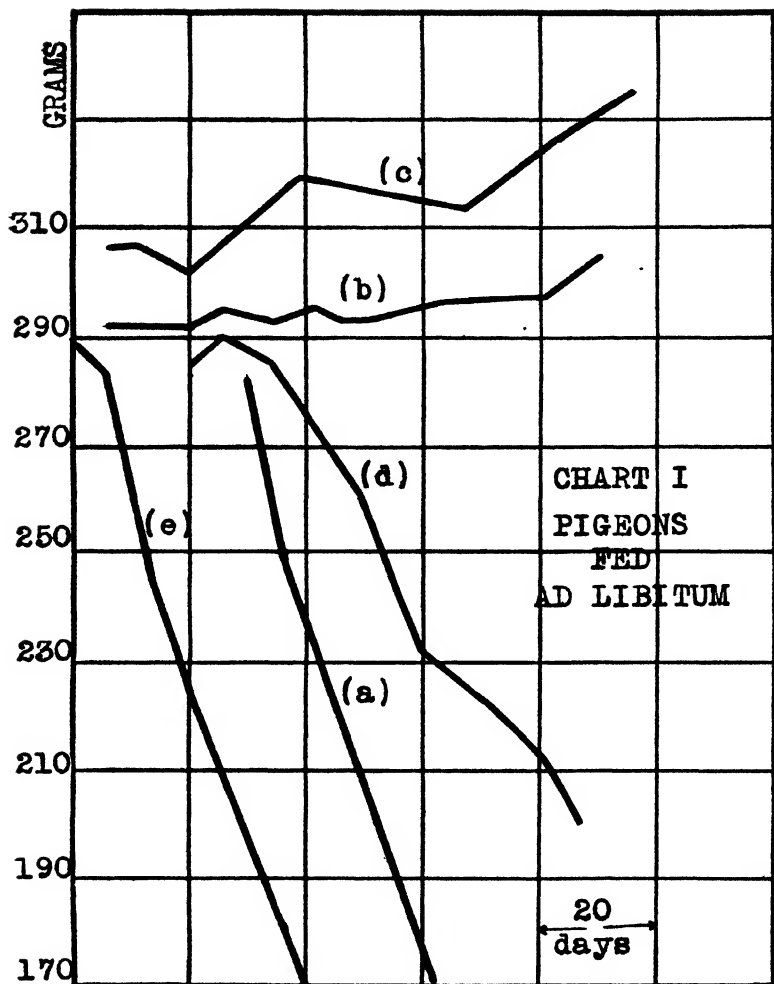


CHART 1. Represents the average body weight of the different groups that were fed *ad libitum*. Curve (a) for the milled rice; (b) for the unheated unmilled rice; (c) for the unmilled rice heated in the autoclave at 120°C. for 1 hr.; and (d) and (e) for the 2 and 6 hrs. autoclaved rices, respectively.

The heating for 1 hr. in the autoclave (Curve (c)) had no detrimental effect on the antineuritic vitamine. In the case of the 2 and 6 hrs. autoclaved rices, the losses in weight were very marked, being practically the same as for the milled rice (Curve (a)).

The pigeons on the 6 hrs. heated rice refused their feed and regurgitated part of it sooner than the ones that were fed on the 2 hrs. autoclaved rice. The general symptom complex of these two groups of pigeons was very similar to that observed in the feeding of milled rice.

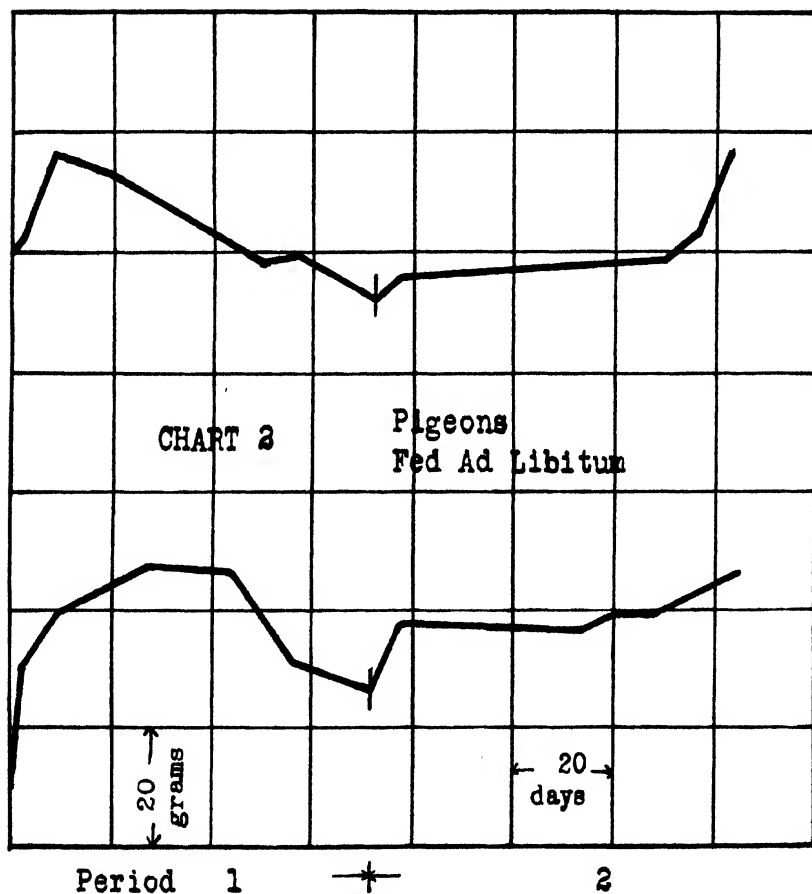
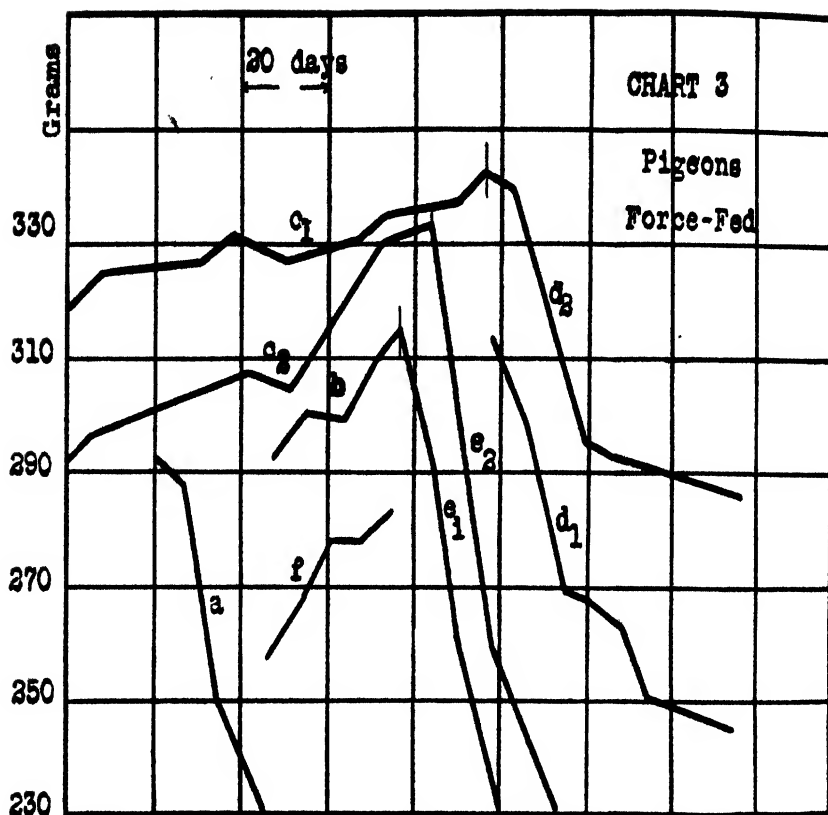


CHART 2. Shows the average weight curves for pigeons that were fed *ad libitum*, Period 1 unmilled rice heated for 2 hrs. at 120°C. in the air oven and Period 2 on the rice that was heated in the autoclave 1 hr. at 120°C. There was a gradual loss in weight on the dry heated rice, and only slight symptoms of polyneuritis. Following this, the pigeons gained slightly on the 1 hr. autoclaved rice, just as they did in Chart 1.



(CHART 3. Pigeons were first given *ad libitum* unheated and 1 hr. autoclaved rice (Curves b, c₁, and c₂) respectively. After a time they were force-fed, in some cases on the 2 hrs. autoclaved rice and in others on the 6 hrs. heated rice (Curves d₁, d₂, e₁, and e₂, respectively). In Curve a, they were force-fed the milled rice as a control.

When they consumed the unheated rice they gained, and lost rapidly when force-fed on the 6 hrs. heated rice. Likewise, they gained on the 1 hr. autoclaved rice and lost on the 2 and 6 hrs. heated rice. The pigeons regurgitated some of their food when force-fed, but retained more of it than when they were fed *ad libitum* in Chart 1. That this loss in weight was not due to the mechanical handling of the pigeons in force-feeding them is evidenced from Curve f where they were force-fed on unheated unmilled rice and gained.

The curves show that even though the pigeons consumed more of the 2 and 6 hrs. autoclaved unmilled rice than when fed *ad libitum*, the extra amount had no value.

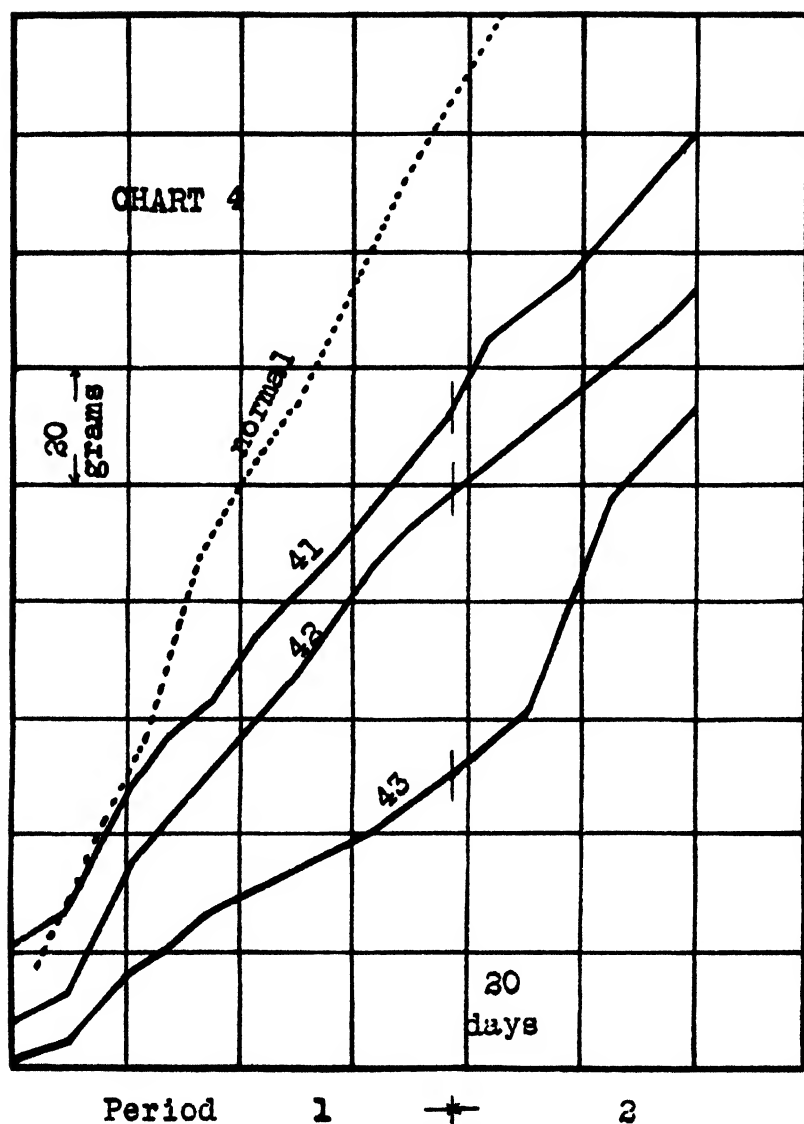


CHART 4. The rats were fed the basal diet of unheated unmilled rice, supplemented with lactalbumin, salt mixture, butter fat, and lard. The protein plane was 10 per cent. In Period 1 the rice formed 64 per cent of the ration and in Period 2, 89.7 per cent.

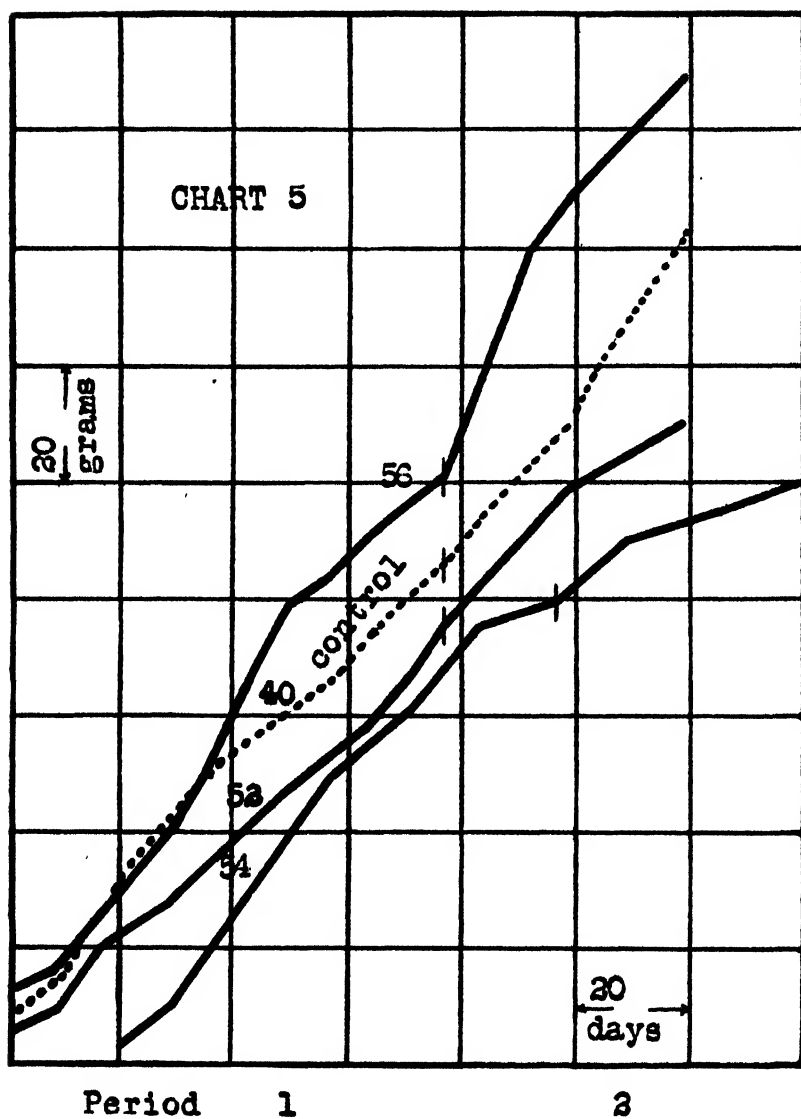


CHART 5. The rats were fed the basal diet of unmilled rice heated 2 hrs. in the air oven at 120°C. Otherwise the ration was the same as for Chart 4. The control, Curve 40, is the average for the curves for the unheated rice (Chart 4).

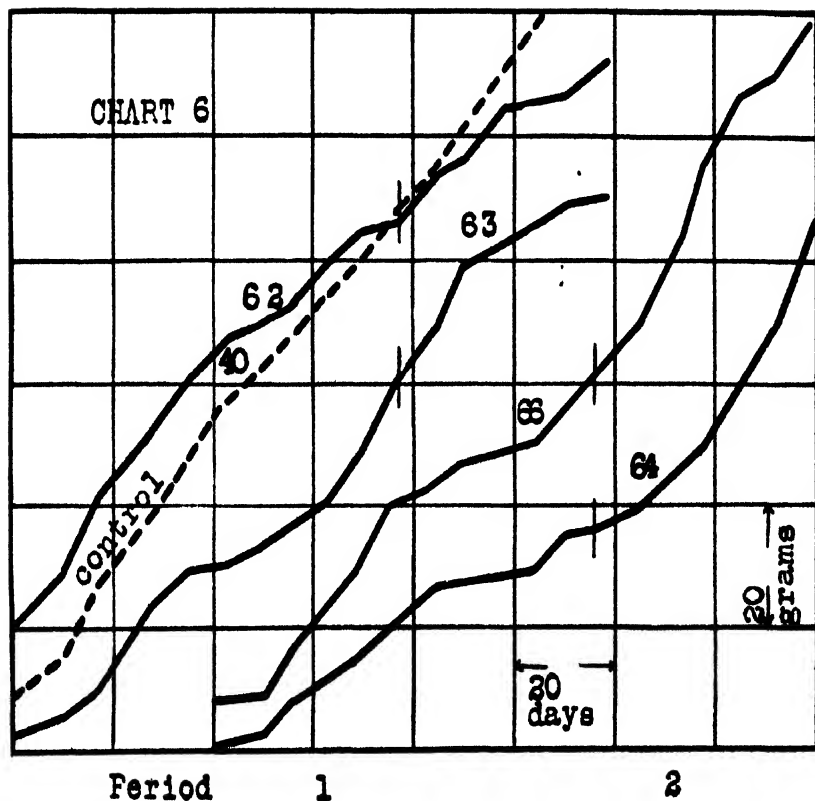


CHART 6. Same as Chart 5, except the basal rice diet was heated 2 hrs. in the autoclave at 120° and 15 pounds pressure.

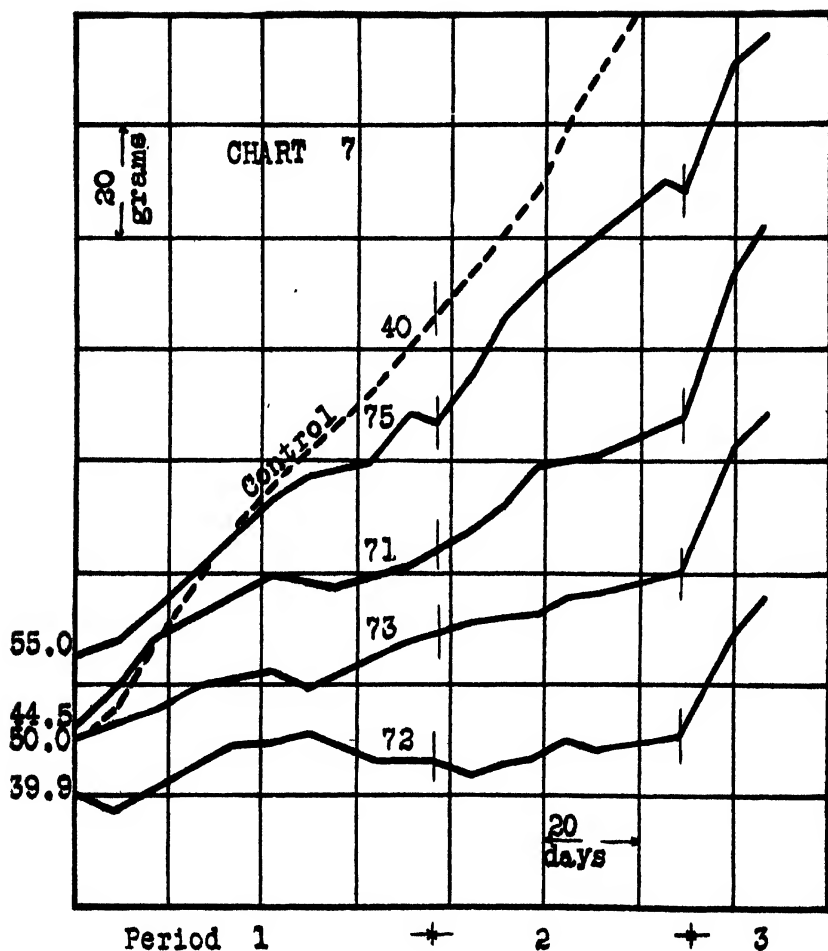


CHART 7. Same as Chart 6, except the rice was heated for 6 hrs. in the autoclave at 120° and 15 pounds pressure. In Period 3, the rats were fed the same ration as in Chart 4.

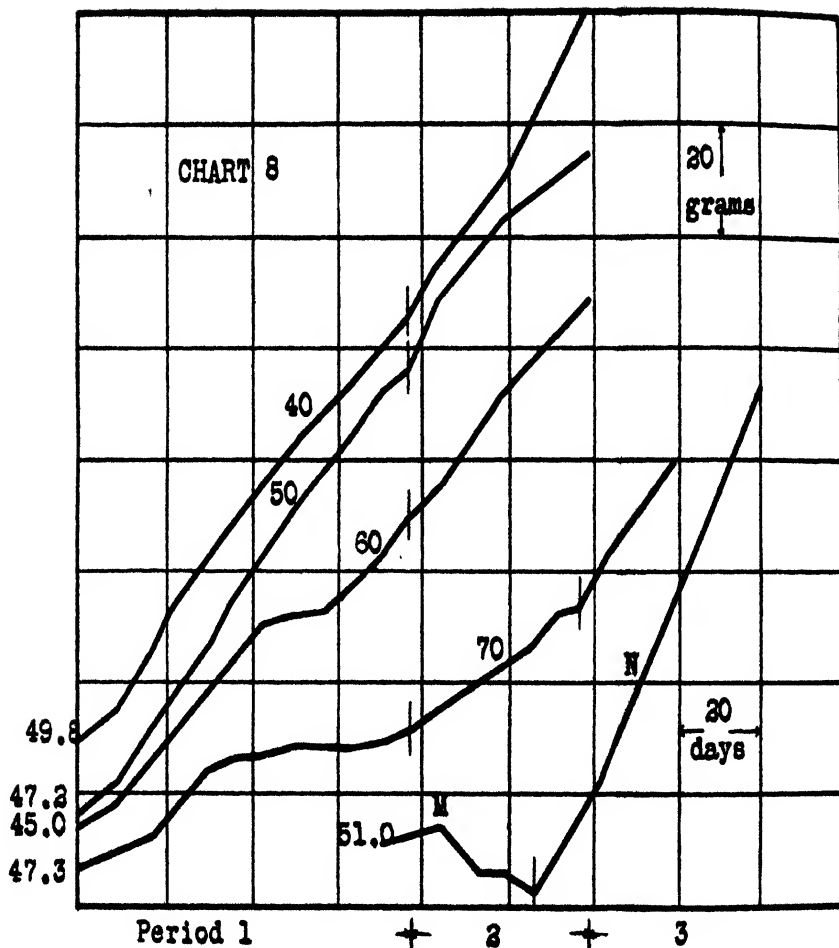


CHART 8. The average curves show that the growth-promoting vitamin was not altered by heating at 120° for 2 hrs. in the oven. Thus, Curve 50 ran parallel with that for the unheated rice (Curve 40). In the case of the 2 hrs. autoclaved rice, heated at 120° and 15 pounds pressure, Curve 60 ran practically parallel with the other two, except for a short period. The curve for the 6 hrs. heated rice (Chart 70) shows some gain. In all four groups, there was a definite gain.

If the growth-promoting water-soluble vitamin had been destroyed by heat, the resultant effect in these four curves would have been a decline in weight the same as for the first part of the control, Curve MN where rats were first (M) fed on a ration composed of butter fat, lard, starch, lactalbumin, and salt mixture without any of the so called water soluble B, and later (N) given this vitamin.

55.0
44.5
50.0
39.9

124
C1

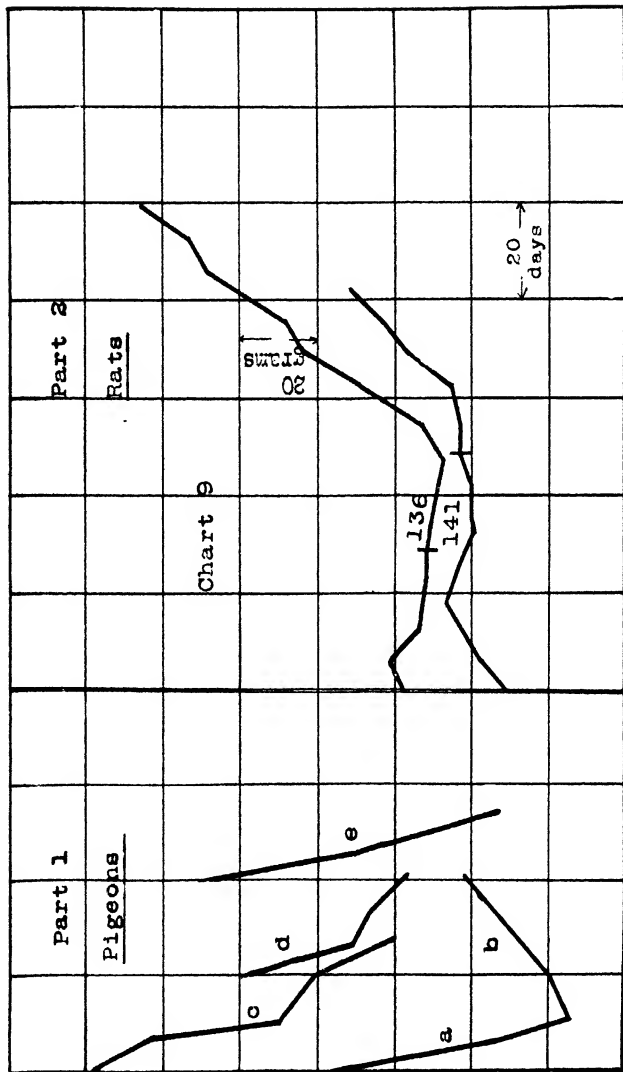


Chart 9. In Part 1, the pigeons were all force-fed milled rice. In the case of Curve a, they were not treated until there were definite signs of typical polynucleosis. Then the pigeons were treated with unheated vitamin extract. In Curves c, d, and e, the pigeons were treated from the beginning every other day with equivalent amounts of the extracts that had been heated 2 hrs. at 120° in the air oven, 2 hrs. at 120° in the autoclave, and 6 hrs. at 120° in the autoclave, respectively. The evidence is quite conclusive that heating under these conditions destroyed the vitamin. In fact, the vitamin in the extract was undoubtedly broken down more quickly than in the rice.

In Part 2, the same vitamin extract after heating 6 hrs. in the autoclave at 120° was incorporated in a ration that was deficient in the water-soluble growth-promoting factor. The fore period shows that the rats were not growing while the test period indicates that they began to grow after adding the extract indicating that this vitamin was not totally destroyed by the heating.

WATER-SOLUBLE VITAMINES.

II. THE RELATION OF THE ANTINEURITIC AND WATER-SOLUBLE B VITAMINES TO THE YEAST GROWTH-PROMOTING STIMULUS.*

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With the idea of making a further study (1) as to whether the antineuritic and the water-soluble B vitamins were different, we endeavored to apply one of the two yeast quantitative methods that have been proposed. We selected the Williams (2) micro method which the author claims measures qualitatively and quantitatively the presence of the antineuritic vitamin. Bachmann's fermentation method (3) has been used by Eddy (4).

The plan of approaching this phase of the problem was similar in some respects to that which we used formerly (1); that is, a study of the effect of heat on the water-soluble vitamins. Comparative trials were made to determine whether or not the extracts that caused increased growth of the yeast would cure polyneuritis in pigeons, or excite growth in young rats that were suffering from a lack of the water-soluble B vitamin.

Briefly, this micro method¹ was as follows: (a) Preparation of synthetic media-- saccharose, 20 gm.; $(\text{NH}_4)_2\text{SO}_4$, 3 gm.; KH_2PO_4 , 2 gm.; asparagine, 3 gm.; CaCl_2 , 0.25 gm.; and MgSO_4 , 0.25 gm., all made up to 1 liter with distilled water. The reagents were purified. The media was sterilized at 10 pounds pressure for 10 minutes and kept in the refrigerator. (b) Procedure: A suspension was made of yeast cells in about 30 cc. of sterile distilled water. Duplicate test solutions were prepared quantitatively by taking 25 cc. of the synthetic media and 1 to 5 cc. (depending upon the concentrations) of a definite solution of the unknown extract. This was

* Proceedings of the American Chemical Society, St. Louis, April, 1920.

¹ The authors desire to express their appreciation to Professor F. C. Koch, of the University of Chicago, for the privilege of permitting us to become familiar with the technique of the details of this method.

diluted to 30 cc. (using sterile water if needed). The mixture was sterilized and 1 cc. of the yeast suspension added. After mixing, thirty-six drops were made with a fine pen point on a cover slip that had been coated with a very thin film of purified vaseline. This slip was inverted and sealed tightly on a hanging drop slide. Each drop was examined for single yeast cells, the observations were recorded, and the time was noted. The slide was then placed in the incubator at 30°C. and the readings were made again in 18 hours. In case the number of cells in each drop at the end of this period exceeded 75, the determination was repeated using less of the unknown. Similar tests were run on the synthetic media as a control. After correcting for this blank determination, the rate of growth in terms of yeast cells was calculated per gm. of the original unknown material.

TABLE I.

Preliminary Tests with the Williams Micro Yeast Method.

Concentration of solution of vitamine extract No. 2650.	Amount added to media.	Average reading of yeast cells.*	Yeast cells per gm. of original substance.	Average of duplicate cells per gm. of substance.
<i>per cent</i>	<i>cc</i>			
A. 0.02 made from a 5 per cent solution by dilution.	1 0	7 8	39,000	39,750
	1.0	8.1	40,500	
B. 0.02 made from a 5 per cent solution by dilution.	3 0	23 8	39,500	39,250
	3 0	23 6	39,000	
C. 0.02 made directly.	3.0	23 6	39,000	39,500
	3 0	24 0	40,000	
D. 0.2 made from a 5 per cent solution by dilution.	3.0	82 2	38,600	38,650
	3 0	82 4	38,700	
Average				39,287

* Corrected for control reading on reagents.

Table I gives an idea as to the accuracy of the Williams method. It will be seen, in varying the concentration of the solution, or in taking different quantities of the same solutions, that not only the duplicates in any one series but the corresponding final average values in the different series agreed remarkably closely for such a biological method, showing that this method can be used with definiteness for measuring the rate of growth of yeast.

DISCUSSION.

The Yeast Growth-Promoting Factor Is Not the Antineuritic Vitamine.—In making these tests, natural or unmilled rice was heated as follows: 1 hour in the autoclave at 120° and 15 pounds pressure; 2 hours in the autoclave at 120°; and 6 hours in the autoclave at 120° and 15 pounds pressure. These rices, together with some of the unheated rice, were finely ground, then extracted with hot 95 per cent alcohol. These extracts were concentrated *in vacuo*, taken up with hot water and salt, then filtered, and made up to a definite volume. The tests were then made upon

TABLE II.
Effect of Heat on Yeast Growth-Promoting Vitamine.

Extracts of natural rice	Average reading of each determination.*			Average yeast cells per cc	Yeast cells per gm of original rice
	1 cc	3 cc	4 cc		
Unheated rice.	12 7 12 3	38 0 38 7		12 6	63
1 hr. in autoclave at 120°C.	12 9 13 1			13 0	65
2 hrs. " " 120°C.	12 8 12 9	37 7 37 1		12 6	63
6 " " " 120°C.	13 1 13 1		49 6 49 0	12 7	64

* Corrected for control reading on reagents.

these solutions, blank determinations being carried out with the same dilution of salt and synthetic media. Corrections were applied in making the final calculations. No data are included with respect to comparing heated extracts that originally contained the antineuritic vitamine. We found that this extracted vitamine was apparently more unstable to heat than when in the natural food.

The data are presented in Table II. They indicate very clearly that the factor which stimulated growth in the yeast was not altered in the least by the process of heating. This obser-

vation was contrary to what we had expected, since Williams (2) designated the yeast growth stimulus as the antiberi-beri vitamin. From previous findings (1) we have already concluded that the extensive heating of the rice (2 and 6 hours in the autoclave at 120° and 15 pounds pressure) altered in a very marked way the potency of antineuritic vitamin. Therefore, we naturally expected the activity of the extracts, in terms of yeast cells, to decrease with the higher degree of heating.

TABLE III.

Potency of Extracts from Natural Rice on Polyneuritic Pigeons.

Extract of natural unmilled rice	Pigeon No	Equivalent yeast cells given in extract	Yeast cells per gm. of body weight	Response to treatment.
Unheated.	510	10,269	41	Cure.
	803	7,812	31	"
Average.			36	"
2 hrs. in autoclave at 120°C.	805	9,750	38	No improvement, died.
	793	9,750	38	" " "
Average.			38	" " "
6 hrs. in autoclave at 120°C.	735	10,400	42	No improvement, died.
	781	10,400	33	" " "
Average.			38	" " "

In order to prove this point more definitely, the antineuritic property of the extracts of these rices was tested by treating polyneuritic pigeons with equivalent quantities of each extract in terms of the number of cell units per gm. of body weight. These data are presented in Table III.²

There is, of course, a possibility that in the heating of the rice some toxic substances were formed which were removed in the extraction along with the vitamin and in turn prevented the antineuritic vitamin from acting on pigeons. If so, one would expect the yeast growth-promoting vitamin to be affected in

² In making these tests the pigeons selected showed the usual definite signs of typical advanced polyneuritis. The "cure" cases remained positive for 7 to 10 days which is sufficient for a definite test of the potency of an extract.

the same manner, but it was not. On the other hand, with the yeast cell stimulus, we have found that some extracts contain toxic factors although the antineuritic and the water-soluble B vitamins were shown to be present by biological tests. As a result, the readings were very misleading as shown in Table IV.

The Yeast Growth-Promoting Factor Apparently Does Not Stimulate Growth in Young Rats.—In order to obtain an idea as to the amount of the yeast stimulus that normal rats require, the value

TABLE IV.
Toxicity in Relation to the Yeast Growth-Promoting Stimulus.

No of extract.	No of yeast cells in diluted solution.	
	1 cc.	3 cc
30-40	12 7-12 8	7 8-8 7
	12 75	8.25
30-50	10 9-11 0	7.3-8 9
	10 95	8 1
1,339 (2 hrs. in autoclave at 120°C.)	9 5-13 5	11 9
	11 5	
1,339 (6 hrs. in autoclave at 120°.)	13 2-13 9	11 7-11 9
	13 55	11 8

was calculated from previous prophylactic feeding experiments where rats were fed as their basal diet natural rice (1). The data are given in Table V.

In making the tests to determine whether or not the rats would be stimulated to grow on a definite number of yeast cell units, a water-soluble vitamin preparation was activated with fuller's earth by the Seidell method (5). The filtrate was found to contain 2,537 yeast cell units or 6.4 per cent of the total yeast factor. Failure to cure pigeons showed that its antineuritic vitamin content was extremely low.

TABLE V.

Calculated Yeast Cell Units Consumed by Normal Rats.

Substance.	Group of rats.	Yeast cell units per day per gm	Remarks.
Natural rice, unheated.	40	3 0	Gained in weight.
“ “ 2 hrs. dry heat at 120°.	50	3 3	“ “ “
Natural rice, 2 hrs. autoclaved at 120°.	60	3 3	“ “ “
Natural rice, 6 hrs. autoclaved at 120°.	70	2 7	Moderate gain in weight.

Rats that had been brought down to a low nutritive plane, due to a lack of the so called water-soluble B, were treated with 1 to 1.5 cc. of this filtrate. As the rats were weighed daily, it was found (Table VI) that Rats 834 and 835 both lost in weight during the 15 days treatment. Further, in the case of Rat 735, its loss in weight was so marked that we were forced to give it a treatment of the original vitamin extract whereupon it immediately began to gain.

Following the first treatment of Rats 834 and 835 with an extract from the 6 hours autoclaved 120° natural rice, they stopped

TABLE VI.

Relation of Yeast Cell Units to Growth of Rats.

Substance	Rat No.	Yeast cell units per day per gm	Remarks
Extract 7,000.5b-Filtrate fullers' earth.	834	7 0	Weighed 47 gm. Lost 4.2 gm. in 15 days.
Extract 6 hrs., autoclaved 120° natural rice.	834	7 5	Gained 3.0 gm. in 5 days.
Extract 7,000.5b-Filtrate fullers' earth.	835	7.8	Weighed 35.5 gm. Lost 4.0 gm. in 15 days.
Extract 6 hrs., autoclaved 120° natural rice.	835	6.9	Gained 10 gm. in 5 days.
Extract 7,000.5b-Filtrate fullers' earth.	735	15 3	Weighed 49.5 gm. Lost 6.4 gm. in 3 days.

losing and began to gain on doses that were equivalent in yeast cell units to what they were given of Extract 7,000.5b.

In Table VII, further data are presented with respect to the amount of extract, in terms of yeast cell units, that were required to make a rat grow. These two rats, Nos. 673 and 675, were so far down from a lack of the water-soluble B that they had reached that condition which is described by some as polynneuritis.

It is thus seen that the rats in the curative or corrective tests (Tables VI and VII) were given 2 to 2.5 times as much of the

TABLE VII.
Relation of Yeast Cell Units to Growth of Rats.

Substance.	Rat No	Yeast cell units per gm.	Remarks
Extract 2 hrs. autoclaved 120° natural rice.	673	14*	Weighed 7.2 gm. Lost 9.2 gm. in 5 days.
Extract unheated natural rice.	673	14	Gained 25 gm. in 19 days, following one treatment only.
Extract 2 hrs. autoclaved 120° natural rice.	675	14*	Weighed 99.7 gm. Gained 11 gm. in 5 days.
Extract unheated natural rice.	675	14	Gained 20 gm. in 19 days, following one treatment only.

* Given every 2nd day.

yeast cell units in Extract 7,000.5b as those on the prophylactic tests (Table V) yet they did not respond and grow. This suggests that either the yeast cell stimulus was not the same as the water-soluble B, or that the rats in this condition required more of it. When the dose was increased to almost five times, Rat 735 refused to grow. This led us to infer that there was some factor involved in the growth of the rat other than the yeast cell units, or at least to conclude that the yeast cell stimulus was not in itself able to retard the loss in weight and excite growth, measured by increase in weight of rats. As a further proof of this, the data in Table VII tend to show that, with the amount

and kind of extract used, the water-soluble B vitamin had a specific action on the growth of the rat that the yeast stimulus lacked.

This statement is not intended to convey the idea that the stimulus or vitamin which certain varieties of yeast seem to utilize is not needed by the rat or the pigeon for some other definite purpose or purposes in their physiological economy. Our data do not lend themselves to an interpretation of this point.

CONCLUSIONS.

1. The rate of growth of the yeast which we employ is strikingly accelerated by the addition to the synthetic media of very small amounts of preparations, which we have shown by biological tests to contain the antineuritic and the water-soluble B vitamins, provided certain toxic substances are absent.

2. The yeast growth-promoting factor does not appear to be the same as the antineuritic or antiberi-beri vitamin (pigeons).

3. This yeast stimulus is also possibly different from the water-soluble B growth-promoting vitamin (rats).

4. Whether pigeons or rats require this yeast growth-promoting factor for normal development has not, as yet, been definitely proved.

5. Since the amount of yeast growth stimulus, expressed in terms of yeast cell units per gram of substance, does not appear necessarily to vary directly (in terms of potency) with the antineuritic and water-soluble B vitamins, this yeast method should not be employed quantitatively with too much definiteness until further study is made.

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STUDIES IN THE VITAMINE CONTENT.

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In 1917 the results of experiments conducted at the New York Hospital with vitamine B dosage in cases of infant malnutrition demonstrated the necessity for some method of controlling this dosage. At that time the senior author reported some experiments to this end, using the Folin-Macallum uric acid reagent for the purpose.¹ This work was interrupted by the war and on resuming investigation in the fall of 1919 attention was directed to two publications bearing upon this subject and suggesting the utilization of the vitamine requirement of yeast as the measuring medium.²

In the Fall of 1919 we began a systematic investigation of these two methods to determine their practicability for the measurement of the B vitamine. Our earlier studies were with the Bachmann technique followed by a similar study of Williams'. Our observations led finally to the evolution of a new technique which utilizes features of both these authors' methods but we believe eliminates some of the features that made their tests difficult of quantitative control. The various steps have been reported from time to time³ but are here collated in full.

The Practicability of the Bachmann Test.

The methods adopted were practically those suggested by Bachmann. Fermentation tubes were filled with Nægeli solu-

¹ Eddy, W. H., *Proc. Soc. Exp. Biol. and Med.*, 1916-17, xiv, 164.

² Bachmann, F. M., *J. Biol. Chem.*, 1919, xxxix, 235. Williams, R. J., *J. Biol. Chem.*, xxxviii, 465.

³ Eddy, W. H., *Proc. Soc. Exp. Biol. and Med.*, 1919-20, xvii, 52, and two other articles in press.

tion (100 cc. of distilled water, 10 gm. of dextrose, 1 gm. of ammonium nitrate, 0.05 gm. of calcium phosphate, 0.5 gm. of potassium acid phosphate, 0.25 gm. of magnesium sulfate) and sterilized in the Arnold sterilizer. The vitamine extracts were prepared from navy bean by the method described by McCollum and Simmonds.⁴ This method yielded the vitamine in alcohol extract, and this extract was either evaporated down on dextrin and a water solution of the activated dextrin used or was simply evaporated to dryness and a water solution of the residue used. The concentrations were controlled by varying the amount of

TABLE I.

Tube No.	Tube contents.	Per cent of gas formation by days									
		1	2	3	4	5	7	8	9	14	
1. Control.	Nageli solution plus yeast (Control 1).	0	0	0	0	0	0	0	0	0	
2. “	Nageli solution plus yeast plus 1 cc. dextrin solution (Arnold).	0	0	0	0	0	0	0	0	0	
3. “	Nageli solution plus yeast plus 1 cc. dextrin (Arnold and autoclave).	0	0	0	0	0	0	0	0	0	
4. Test.	Nageli solution plus yeast plus 1 cc. dextrin-vitamine solution (Arnold).	0	90	87	63	18	Discontinued.				
5. “	Nageli solution plus yeast plus 1 cc. dextrin (Arnold and autoclave).	0	93	85	56	56	40	37	37	33	

water. All such extracts were sterilized in the Arnold sterilizer and the sterile extract was introduced in appropriate amounts into the fermentation tubes. The tubes were finally inoculated by a loopful of a yeast suspension made from a pure culture of Fleischmann yeast. In certain cases unextracted material was used but in all cases the material was sterilized before testing. The first results are shown in Table I. In the experiments a watery solution of the activated dextrin obtained from navy bean was used. The solutions in Tubes 2 and 3 consisted of water solutions of unactivated dextrin of the same concentration as the

⁴ McCollum, E. V., and Simmonds, N., *J. Biol. Chem.*, 1918, xxxiii, 55.

dextrin in Tubes 4 and 5. Two methods of sterilization were used, one (Arnold) being a submission of the extract to two 30 minute periods in the Arnold sterilizer at 100°C., 24 hours elapsing between the two periods, while the other (Arnold and autoclave) added a third 30 minute period in the autoclave at 15 pounds pressure and approximately 120°C.

These first results demonstrated Bachmann's point that gas formation fails to result in the absence of an extract containing the B vitamine, if we assume that the substance in the extracts of Tubes 4 and 5 responsible for the effects is the vitamine. The reduction in gas on successive days is due to the absorption of the

TABLE II.

Comparison of Concentrations by the Bachmann Method.

Concentrations Days	Arnold-sterilized solutions.												Arnold- plus autoclave-sterilized solutions.											
	Series I.				Series II.				Series III.				Series I.				Series II.				Series III.			
cc.	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4
1	0.90	87	63	18		0.99	100	85	0.68	100	82	0.95	85	58	56	0.99	100	65	0.68	100	80			
0.5	0.95	91	85	68		0.95	100	99	0.53	95	95	0.26	51	58	25	0.60	100	84	0.23	100	96			
0.2	0.16	63	29	11		0.2	35	29	0.1	78	99	0.50	70	35	72	0.0	18	30	0.0	75	67			
0.1	0.0	0	0	0		0.0	0	1	0	0	0	0.0	0	0	0	0.0	0	0	0.0	0	0			

CO₂ back into the medium on standing, probably a siphoning action which begins as soon as saturation is complete. This feature is one of the hindrances to accurate quantitative comparison by this method but if this had been the only objection it could have been easily obviated.

The results in Table II indicate that below the optimum concentration the gas formation varies with the concentration and was the first indication that in comparing solutions it is first necessary to determine the dilution necessary to produce optimum results since amounts above that do not appreciably affect the strength of the reaction. In the above tests watery solutions of activated dextrin with the navy bean as source were used. The variations in the different series were probably due to the amount of yeast used in

the inoculations and pointed out the necessity of standardization in this particular for truly quantitative comparisons. The autoclave seems to reduce the activity slightly when the concentration is under the optimum but the results in this respect are extremely inconclusive from the evidence given above. The tests were ended when the maximum gas production was reached.

A Cream of Wheat extract was made in the same manner and with the same amount of wheat as was taken of navy bean in the preceding tests. The results in Table III are interesting in showing that Cream of Wheat while largely endosperm responds markedly to the test. The protein-free milk was not from Walker-Gordon material; the amount used was comparable, however, to 1 cc. of whole milk. The variability of the vitamine content in milks of

TABLE III.

Application of the Method to the Qualitative Analysis for Vitamine.

Substances tested	Per cent gas formation by days						
	1	2	3	4	5	6	7
1 cc. vitamine extract of Cream of Wheat.....	0	60	100	83	33	28	
$\frac{2}{3}$ " protein-free milk.....	0	20	40	53			100
1 " Walker-Gordon whole milk.....	0	100	100	100	100	60	
1 " " " " (duplicate)...	0	68	100	100	66		
0.5 " " " " "	0	52	100	68	50		
0.3 " " " " "	0	25	60	50	32		

different sources is well borne out by this experiment. Arnold sterilization alone was used on all the above products. The results in Table IV leave no doubt that cow's milk is richer in vitamine than human milk in the concentrations used; that is, without dilution or concentrating. When, however, we attempt to compare the results of the different tests the variability in the human milks is disconcerting. In Series I of Table IV the strength is ACDBEF. In Series II with the same concentration it is ADECBF. When the amounts are reduced to 0.5 cc. as in Series III the results are (BD)EFC'A. Such variations indicate that when vitamine contents are of nearly the same magnitude the test is unreliable in the form in which we have used it.

From these and other tests that need not be recorded here, we feel that the Bachmann technique is in need of considerable modi-

fication if it is to be used for quantitative comparison of vitamine content. Furthermore, since the activity of an enzyme is so easily varied by hydrogen ion concentration and by other factors, we abandoned this method at this point to experiment with the Williams technique.

TABLE IV.

Comparison of Walker-Gordon Whole Milk (Cow) and Six Samples of Human Milk from Six Different Sources; Bachmann Method.

Substances tested.	Per cent of gas formation by days.														
	Series I.					Series II.					Series III (0.5 cc.).				
	1	2	3	4	5-6	1	2	3	4	5-6	1	2	3	4	5-6
1 cc. Walker-Gordon cow milk.....	0	100	100	100	60	0	68	100	100	86	0	52	100	68	50
1 cc. breast milk A. . . .	0	12	63	80	100	0	0	60	100	68	0	0	100	10	30
1 " " " B. . . .	0	21	59	70	70	0	31	70	72	62	0	0	24	65	90
1 " " " C.	0	17	47	68	82	0	8	82	60	65	0	3	32	50	48
1 " " " D.	0	31	72	72	72	0	65	90	80	70	0	0	28	78	90
1 " " " E.	0	1	23	56	65	0	5	70	90	65	0	0	20	68	64
1 " " " F. . . .	0	0	20	35	59	0	3	78	72	45	0	0	48	68	50

*Experiments with the Williams Technique.*⁵

By substituting for gas formation the actual increase in yeast cells as the unit of measurement, this test eliminates the variability in enzyme activity as a controllable factor. In practice we found it was an exceedingly difficult matter to dip out with a pen, as directed by the author, drops containing uninjured single cells. Secondly, it was not easy to be sure of our count under the microscope and, finally, incubation resulted in evaporation and made it difficult to control accurately the quantities of extract measured for the test. For all these reasons we sought a simpler method, more easily controllable but retaining the cell count method for comparisons.

⁵ At the time this article was submitted, the gravimetric method (Williams, R. J., *J. Biol. Chem.*, 1920, xlii, 259) had not appeared.

A New Technique for the Measurement of Vitamine Content.

Fig. 1 shows the tools used, being essentially those of the opsonin technique. The first step in the preparation is the manufacture of a pair of capillary pipettes. These are made by drawing out in the flame a piece of 5 mm. soft glass tubing. At the center of the capillary portion a mark is made and with a drop of

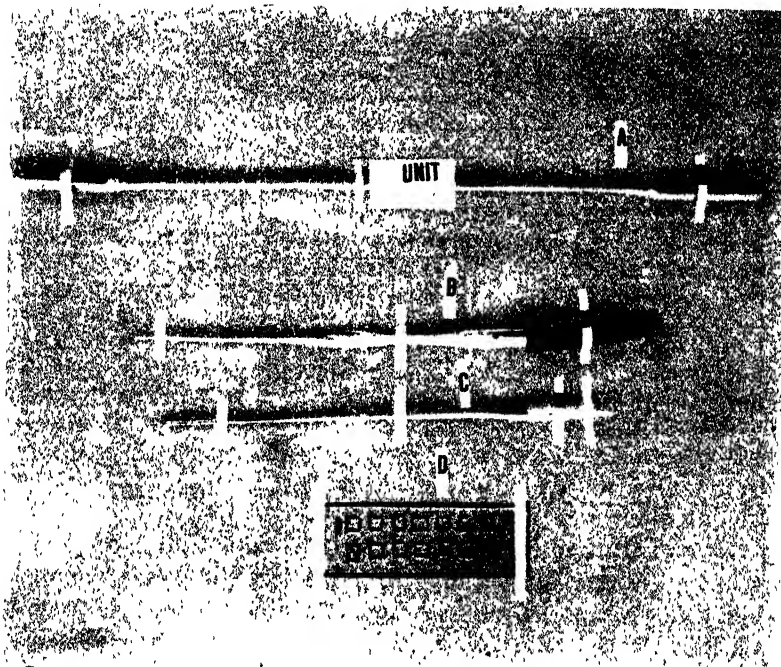


FIG. 1.

mercury two units are marked off on each side of this center. Our unit was chosen arbitrarily and consisted of a drop of mercury weighing 0.0108 gm. and occupying a volume of approximately 0.0007 cc. The tubes, after calibrating, were cut apart at the center. Each pipette is then constricted in the flame at a point near the large end to permit of a flame seal here later. The large end is then plugged with cotton and the tube sterilized. By fitting a rubber bulb to the large end it is ready for use.

Method.

The materials used in the test are the capillary pipette described above, a dilute suspension of yeast cells in Nægeli solution, and a sterile solution of the vitamine extract to be tested. Miss Stevenson investigated some thirty strains of yeast to determine their relative suitability for the test and found that the one obtainable from a Fleischmann yeast cake was as good as any for the purpose. Since this yeast is readily available at all times we adopted it for our purpose. A pure culture of this yeast is maintained on an agar slant. 48 hours before beginning the test a transplant is made to fresh agar and at the end of the 48 hours as small a portion as can be taken up on the tip of a needle is transferred to 10 cc. of Nægeli solution. The tube is then shaken for 2 to 3 hours in a mechanical shaker. This process does not give absolutely uniform suspensions and occasional clumps are found. Slow centrifuging will remove most of the clumps, however, and this method has been found satisfactory for results if controlled by a sufficient number of tests. For the perfection of the test it is eminently desirable to find a method of making a uniform yeast suspension and we are still experimenting with this difficulty. The uniformity of the suspension is tested before use by drawing up with the pipette five to ten units of the suspension and blowing them out on a glass slide where they are fixed, stained, and the cells counted. If the test shows fair uniformity the suspension is used, otherwise it is shaken further and the test repeated.

As soon as a fairly uniform suspension is obtained, the rest of the process is simple. First, prepare and sterilize as many pipettes as are needed for the test. Second, sterilize the vitamine extracts to be studied. When all are ready draw up into the pipette one unit of yeast suspension and one unit of the vitamine extract, mix by manipulating the bulb, seal the tip of the pipette in the flame, and make the flame seal at the constriction. The tube is now ready to incubate. The time of incubation varies with the strength of the solution to be tested but we have usually incubated the tube 20 hours at 35°C. At the end of that time the tips are broken at each end of the pipette, a bulb is placed on the large end, and the contents are blown out on a slide, fixed, and stained. The counting can then be done accurately at leisure. For a count-

ing slide we have etched 5 mm. squares on an ordinary microscope slide as shown in Fig. 1. This size holds the contents of a pipette, permits ease of operation when counting with the mechanical stage, and allows the contents of ten to twelve pipettes to be placed on one slide.

For control, another series of pipettes is prepared and filled by drawing up a unit of the yeast suspension without the unit of vitamine. These are incubated and counted in the same manner as the test pipettes. Obviously the greater the number of pipettes used the more accurately the results can be plotted. Tables V to XIV illustrate the excellencies and defects.

TABLE V.

Series.....	I	II	III	IV	V	VI	VII	VIII	IX	Size unit.
No. units yeast suspension....	1	1	1	1	1	1	1	1	1	cc
No. units vitamine.....	2	2	2	2	2	2	1	1	2	0.0007
Period of incubation, hrs. . .	24	24	18	18	18	18	18	18	6	
Result (vitamine)	6,312	3,192	6,161	9,724	6,348	8,531	472	362	24	
" (control)...	5	28	14	123	46	97	58	60	2	

Evidence Bearing on the Specificity of the Test.

Table V demonstrates that our test was sensitive to small amounts of vitamine extract. Before going farther with the test, however, it was imperative that we demonstrate as far as possible the specificity of the reaction. To this end we applied the test to samples of the purified crystalline antineuritic vitamine prepared by Funk in 1912 and 1913 by his fractional precipitation methods, and kindly furnished by him for the purpose. The results of several tests are presented in Table VI. The marked activity of the 1913 (II) preparation was indicated, the inactivity of the 1912 sample, and the possible activity of the 1913 (I) portion. To settle this latter point new and more concentrated solutions were made of the 1912 and 1913 (I) preparations by dissolving 1 mg. in 0.3 cc. of water and testing a unit of each (Table VII).

TABLE VI.

Series	I	II	III	IV	V
1912 vitamine (1 unit (0.0007 cc.) of a solution contained 0.0124 gm. in 10 cc. of water).....	2	10	11	3	7
1913 vitamine (I) (1 unit of solution contained 0.0145 gm. in 10 cc. of water).....	59	31	41	4	10
1913 vitamine (II) (1 unit of solution contained 0.0065 gm. in 10 cc. of water).....	404	68	322	27	35
Controls.....	113	15	56	4	4

TABLE VII.

Series.....	I	II	III	IV	V
1912 vitamine.....	5	6	87	89	10
1913 " (I).....	206	182	190	149	230
Control.....			24		

The demonstrable impurity in these preparations was nicotinic acid and to determine whether that was the causative factor in the test results were obtained as given in Table VIII.

TABLE VIII.

Series	I	II	III	IV	V	VI	VII	VIII	IX	X	Average.
1 unit nicotinic acid solution made by dissolving 1 mg. in 0.3 cc. water...	81	202	265	5	821	57	84	3917	74.9		
Controls (five pipettes).....			127	94	643		151				84.0
Variations in ten units of the yeast suspension used.....	11	23	135	73	394	8	51	46	54	97	67.4

These results seem to indicate that the nicotinic acid is inactive since the average fails to exceed the controls and the variations are traceable to the variation in the yeast suspension used.

From these results it seems fair to conclude that the test works with small quantities of the Funk antineuritic vitamine as prepared by him in the purest form we have obtained to date and tends to strengthen the conviction that the antineuritic or B vitamine is the responsible causative agent in stimulating the growth of the yeast cells.

Our next step was to utilize the method reported for adsorption of the B vitamine by Seidell and Williams; *viz*, the selective adsorption of Lloyd's reagent. If this reagent adsorbs the B vitamine, a solution tested before and after treatment with the reagent should show marked difference in response. Our first tests in this direction were with a navy bean extract of the vitamine (Table IX).

TABLE IX.

Series.....	I	II	III	IV	V
Navy bean extract before treatment with Lloyd.....	1,927	2,333	672	633	11,237
The same extract after shaking with Lloyd.....	87	64	2	0	100
Controls.....	90	90	15	15	113

We next obtained from an orange, by sterile puncture, a portion of sterile juice. The sterility of the juice was determined by incubating on agar for several days. Portions of this sterile material were then tested before and after shaking with sterile Lloyd's reagent (Table X). It seems evident from these results that the

TABLE X.

Series... ..	I	II	III	IV	V	VI
Orange juice before shaking..	5,200	4,400	62,400	85,700	80,000	19,500
“ “ after “ ..	169	176	109	240	301	133
Control average of 5.....					113	

Series.....	VII	VIII	IX	X	XI	XII	XIII
Orange juice before shaking.....	37,200	8,750	89,400	7,350	9,500	2,800	8,300
Orange juice after shaking.....	159	163	172	28	99	24	232
Control average of 5.....					103		

cause of the stimulus is nearly quantitatively removed from orange juice and from navy bean extract by shaking these extracts with Lloyd's reagent. Since Seidell⁶ has shown that this reagent re-

⁶ Seidell, A., *Public Health Rep.*, 1916, xxxi, 364.

moves the curative factor for polyneuritis these results seem to add to the other evidence that the test is specific for the B vitamin.

Harden and Zilva⁷ have maintained that the Lloyd reagent does not remove the C vitamin. We were concerned to prove that, in the reaction we were using, the stimulus was due to the B and not to the C. If the Lloyd-extracted orange juice still contained the C, it was evident that it was not a factor in the test response. To settle this point we extracted orange juice with the reagent, and then with the assistance of Mr. La Mer of Dr. Sherman's staff we used the filtrate on two guinea pigs. One guinea pig with marked scurvy symptoms, was cured in 12 days with the filtrate.

TABLE XI.

Series.. . . .	I	II	III							
Navy bean extract, Arnold steriliza- tion only.....	1,927	2,333	1,532	1,976	2,375	4,020	112	537	1,416	2,064 987
Navy bean extract, Arnold plus 3 hrs. autoclave	292	294	1,841	2,617	552	12	896	11	3,019	56 321
Controls	40	90	Average 32.							

Average with Arnold alone, 1,668; Arnold plus autoclave, 1,036 (Series 3).

The other, a normal guinea pig, was placed on a scurvy-producing diet and given doses of the filtrate to see if it was protective. This guinea pig is still normal with no signs of scurvy after 25 days. These tests seem to confirm the view that in the juice shaken with Lloyd's reagent there was still plenty of the C vitamin and that it does not give the yeast stimulus.

In the experiments with the Bachmann test we seemed to have some evidence that the causative factor was heat-labile at autoclave temperature but stable at 100°C. We therefore repeated these tests with the new technique (Table XI). These results seem to show that at 120° a partial destruction of the vitamin takes place and becomes visible in the test if the amount of vitamin present is not above the optimum for growth.

⁷ Harden, A., and Zilva, S. S., *Biochem. J.*, 1918, xii, 93.

All authors are agreed that heat plus alkali are destructive of the B vitamine to a marked degree. To test this point and determine whether the cause of our results was alkali-labile, tests were made with results as given in Table XII.

The first test was inconclusive but the succeeding ones seemed to indicate progressive destructive effects with increase in alkali concentration. The objection can be raised that the inhibition was due to the effect of the alkali on the yeast and not on the vitamine, and the results are now being checked by repeating the tests with neutralized mixtures.

TABLE XII.

Series	I	II				
1 cc. navy bean extract plus 1 cc. 0.1 N NaOH.....	146	52	9	5	48	50
1 cc. navy bean extract plus 0.75 cc. 0.1 N NaOH plus 0.25 cc. H ₂ O.....	112	267	27	39	112	
1 cc. navy bean extract plus 0.50 cc. 0.1 N NaOH plus 0.50 cc. H ₂ O.....	170	4,372	96	93	136	
1 cc. navy bean extract plus 0.75 cc. 0.1 N NaOH plus 0.25 cc. H ₂ O.....	116	5,257	364	266	165	

1 unit of each mixture used in the test.

From the above results it seems fair to conclude that the cause of the stimulation of yeast growths in this test is heat-labile, apparently alkali-labile, removable by Lloyd's reagent, and present in Funk's purified antineuritic vitamine mixture. It may of course be something different from the B vitamine but if so it behaves remarkably like that hypothetical substance.

Some Applications of the Test.

Up to the present time we have devoted little attention to applications of the test. A few results, however, have been obtained that bear on important points.

Through the kindness of Dr. N. R. Blatherwick we were given samples of jugular vein and mammary vein plasma from a pregnant cow. This material was studied to determine whether or not the technique was applicable to blood tests, since, if this were

so, the possibility of its application to the distribution of the substance in the body and in organs follows. The plasmas were poured into 75 per cent alcohol, the alcohol was filtered off and evaporated to dryness, and the residue taken up in 10 cc. of water. We had for our use about 10 cc. of each plasma so that the solutions used were comparable in strength to the original plasma. One unit of these solutions was used in the tests (Table XIII). The blood plasmas give the test and the mammary vein seems markedly richer in the causative agent indicating that the mamma, as would naturally be inferred, is a mobilizing point for the vitamine.

Investigations have been started in the estimation of the vitamine content of food-stuffs. The work of Mendel and Osborne³ in their feeding experiments with rats has undertaken the classification of these food-stuffs as to their vitamine B content. Such

TABLE XIII.

Series	I					II					III				
Jugular plasma.....	29	31	44	59	28	46	21	55	30	44					
Mammary "	264	344	623	329	908	858	74	36	1,482	106					
Controls.....	58	48	37	59		24									

substances therefore offer particularly good material for tests since the confirmation of their results would go far toward establishing the practical value of the test in this direction. To enter this field it was first necessary to establish a method of application which would detect relatively slight differences in concentration. Until we can produce absolute uniformity in the yeast suspension it becomes necessary to eliminate the variability in the units of yeast used by increasing the number of tests to a range within the statistical field of accuracy. To that end we adopted the following procedure. First, establish by counting of units the probable range of variation in the suspension used. Second make from five to ten tests on each substance tested and in these test results eliminate all zero readings as showing that the unit in that case contained no cells. Average all other readings. Repeat as often as seems necessary to clear up doubtful po-

³ Osborne, T. B., and Mendel, L. B., *J. Biol. Chem.*, 1919, xxxvii, 187; xxxix, 29; 1920, xli, 451.

sitions. Since it is possible to complete 100 tests, counts and all, in 3 to 4 days, plotted results by this method should approximate to accurate results. It is this work that we now have under way and the results to date follow.

The materials already tested include extracts of alfalfa, potato, onion, radish, cucumber, carrot, celery, tomato, turnip, and apple. These materials were first dried in a 60°C. oven and then pulverized. 1 gm. of each substance in the dry form was extracted for the same length of time in boiling water. The water extracts were filtered and made up to the same volume. These extracts were then sterilized in the Arnold sterilizer. In our first series we used one unit of the extract in each test and five tests on each extract. The reactions were so great that our counts ran into the tens of thousands and made comparisons uncertain. We therefore diluted each extract with five volumes of water and repeated the tests. These results are presented in Table XIV.

TABLE XIV.

Substances tested in order of potency.	Cell counts.					Average.
Alfalfa	76	23	145	18	352	123
Potato	11	97	38	55	37	48
Celery	65	41	41	16	1,312*	41
Apple	28	41	0	53	37	39
Tomato	18	69	0	21	17	31
Cucumber	26	0	0	39	12	29
Turnip	28	33	19	19	42	28
Radish	18	21	23	12	2	15
Onion	2	31	0	5	21	15
Carrot	7	0	6	17	30	15
Controls	3	5	0	12		7
Count of yeast units	4	2	7	1		4

* Not included in the average as obviously due to presence of clump in yeast unit.

They show that in certain of the substances the variations and differences are too slight to rest the case on this one series but they harmonize rather well with feeding results to date in the cases of alfalfa, potato, and tomato. They are given as illustrative of methodology and not of final conclusion.

SUMMARY.

1. This paper presents experiments conducted with both the Bachmann and Williams technique for vitamine measurement and presents a new technique which seems to eliminate some of the difficulties in manipulation of these two tests.

2. Evidence is presented in regard to the specificity of the test that seems to confirm the view that the cause is the B vitamine and that the presence of the C vitamine does not in any way affect the test.

3. Two applications of the test are given as illustrative of its field of application.

DOES GLIADIN CONTAIN AMIDE NITROGEN?*

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(Received for publication, July 1, 1920.)

The Origin of Ammonia Nitrogen in Gliadin.

The amount of ammonia which various proteins yield when hydrolyzed with acids was shown some years ago in a paper¹ from this laboratory to correspond closely to that required for amide combination with the sum of the glutaminic and aspartic acids which these also yield. That the combination $R\text{-CONH}_2$ actually occurs in the protein molecule is not proved by the agreement between the values found by analysis and those calculated, but this agreement was so close that the suggestion then advanced has been generally accepted as probably correct. Recently Thierfelder and von Cramm² have confirmed the evidence just referred to, and contributed further support for this view by experiments with synthetic peptides containing glutamine, as well as with glutamine itself. Additional evidence that the nitrogen which is converted into ammonia by boiling proteins with acids is actually in amide combination is furnished by new experiments which we have just completed.

These were made on the assumption that as $R\text{-CONH}_2$ groups yield free carboxyl groups on hydrolysis the residual products should reveal their presence by an equivalent increase in acidity. Preliminary experiments showed that boiling gliadin with 1 per cent hydrochloric acid for 2 hours yields almost as much ammonia

*The expenses of this investigation were shared by the Connecticut Agricultural Station, and the Carnegie Institution of Washington, D. C.

¹ Osborne, T. B., Leavenworth, C. S., and Brautlecht, C. A., *Am. J. Physiol.*, 1908-09, xxiii, 180.

² Thierfelder, H., and von Cramm, E., *Z. physiol. Chem.*, 1919, cv, 58.

as boiling with 20 per cent acid for 24 hours. The slight increase in free amino nitrogen which occurs during this mild hydrolysis shows that a relatively small proportion of the peptide bindings are broken. Since upwards of 90 per cent of the maximum obtainable ammonia is yielded at a rate strictly proportional to the time of boiling as well as to the concentration of the acid it seems fair to assume that nearly all the ammonia originates from a common group which, like $R-CONH_2$, is very easily hydrolyzed.

Accordingly 5 gm. of air-dry gliadin, equal to 4.7 gm. dried at 110° and containing 0.8125 gm. of nitrogen, were boiled with 500 cc. of 1 per cent hydrochloric acid for 1 hour. The gliadin at first dissolved in the boiling acid, but soon began to separate, finally forming a coherent mass. At the end of the hour 244 cc. of a solution containing 4.9776 gm. of sodium hydroxide were added. The strongly acid solution was vigorously shaken for some time and the suspended solids were then removed by centrifuging and the solution was made up to 1,000 cc. Analysis of aliquot parts showed that this solution contained 9.1720 gm. of solids, of which, after ignition at a low red heat, 7.3770 gm. remained as ash. It also contained 0.1568 gm. of nitrogen as ammonia, equal to 0.8381 gm. of NH_4Cl , if all the ammonia was present as this salt. The total inorganic matter was, therefore, equal to 8.2151 gm., leaving 0.9569 gm. of organic solids in the solution, or 20.3 per cent of the gliadin. The solution contained 0.3171 gm. of N, of which 0.1568 gm. was ammonia nitrogen, the non-ammonia nitrogen consequently being 0.1603 gm., equal to 16.8 per cent of the organic solids. Since in this experiment only 78.0 per cent of the maximum amount of the ammonia obtainable by complete hydrolysis was liberated it is probable that some unchanged gliadin remained dissolved in the acid aqueous solution. This would account for the higher nitrogen content of the soluble organic solids than that calculated for gliadin from which all its amide nitrogen had been split off.

To neutralize 100 cc. of this solution required 0.01428 gm. of NaOH, equal to 0.1428 gm. for the entire solution. The solids removed by centrifuging were suspended in water, and 0.2683 gm. of NaOH was added gradually with vigorous shaking. This was a little more than enough to dissolve all the solids and just sufficed to make the solution neutral to litmus. When 0.0377

gm. more of NaOH was added the reaction became just alkaline in phenolphthalein. In neutralizing the solution and precipitate there were thus added $4.9776 + 0.1428 + 0.2683 + 0.0377 = 5.4264$ gm. of NaOH equivalent to 4.9448 gm. of HCl. Since the ammonia formed by hydrolysis also neutralized a part of the HCl with which the gliadin had been boiled the total base available for neutralizing acid was equivalent to 0.4551 gm. more NaOH, thus making the total equal to 5.8815 gm. Subtracting from this the NaOH required to neutralize the 5 gm. of HCl, namely 5.4869 gm., leaves 0.3946 gm. of NaOH which had been neutralized by acid groups formed during hydrolysis. Since the amount of ammonia found in the solution after hydrolysis was equivalent to carboxyl requiring 0.4551 gm. of NaOH for complete neutralization the amount of NaOH which neutralized the products of hydrolysis to phenolphthalein was 86.7 per cent of the amount calculated for a complete reaction with all the R-COOH groups which would have been formed if all the ammonia originated from R-CONH₂ groups. The acidity developed therefore corresponds to carboxyl groups nearly, if not quite, equivalent to the ammonia produced by hydrolysis.

Since the sum of the amounts of glutaminic acid and aspartic acid which has been obtained from gliadin, the amount of ammonia liberated by hydrolysis, and the increased acidity accompanying the formation of ammonia all correspond closely with the quantities required for nitrogen in amide union with one carboxyl of each molecule of the di-basic acids, there can be little doubt that the ammonia nitrogen is present in the gliadin molecule in amide union with one of the carboxyl groups of each of the glutaminic and aspartic acid groups.

Recently a new question has been raised in connection with this problem by Dakin's³ discovery that some proteins contain oxyglutaminic acid in relatively considerable quantity. This acid might, therefore, afford additional carboxyl groups for a possible amide union. In this connection it is of interest to note that Andersen and Roed-Müller⁴ have described a method whereby the carboxyl groups belonging to di-basic monoaminoacids can be determined in the mixed products of hydrolysis of

³ Dakin, H. D., *Biochem. J.*, 1918, xii, 291.

⁴ Andersen, A. C., and Roed-Müller, R., *Biochem. Z.*, 1916, lxxiii, 326.

proteins. The ammonia and basic amino-acids are removed from the products of hydrolysis and amino nitrogen is determined in an aliquot part of the solution. Another part of the solution is neutralized by Sørensen's formol method, evaporated, and ignited. By determining the carbonate in the ash and calculating its ratio to the amino nitrogen the excess above a 1:1 ratio measures the proportion of dicarboxylic acids. By applying this method to gliadin they conclude that 24.33 per cent of its nitrogen belongs to such acids, whereas the glutaminic and aspartic acids which Osborne and Guest⁵ obtained contained 24.0 per cent. The average of numerous accordant determinations of ammonia nitrogen, namely 24.4 per cent of the total gliadin nitrogen, is in close agreement with the above figures. If gliadin yields appreciable quantities of oxyglutaminic acid this should have been detected by Andersen and Roed-Müller's method. These investigators, on the other hand, found that casein contains an amount of monoaminodicarboxylic acid equivalent to 17.7 per cent of the total nitrogen. This is very much more than Osborne and Guest⁶ found in casein, for the sum of the glutaminic and aspartic acids which they obtained contained nitrogen equivalent to only 10.4 per cent of the casein nitrogen. Foreman,⁷ later, obtained 21.8 per cent of glutaminic acid from casein, a figure since confirmed by Dakin who found in addition 4.1 per cent of aspartic acid and also 10.5 per cent of oxyglutaminic acid. Dakin's results show that casein yields di-basic monoamino-acids containing nitrogen equal to 22.3 per cent of its total nitrogen, or more than twice as much as corresponds to the maximum amount of ammonia yielded by complete hydrolysis. Even omitting Dakin's oxyglutaminic acid, these newer determinations of glutaminic and aspartic acid show the presence of an excess of di-basic acids 50 per cent greater than would suffice for amide combination with the ammonia nitrogen. The marked acidity which, in contrast with most other native proteins, is characteristic of casein may possibly be thus explained.

Andersen and Roed-Müller point out that if all the monoamino-acids in the protein molecule are in peptide union and the di-basic

⁵ Osborne, T. B., and Guest, H. H., *J. Biol. Chem.*, 1911, ix, 425.

⁶ Osborne, T. B., and Guest, H. H., *J. Biol. Chem.*, 1911, ix, 352.

⁷ Foreman, F. W., *Biochem. J.*, 1914, viii, 463.

monoamino-acids occur as amides the products of hydrolysis should be basic, since the carboxyl and amino groups should balance one another, leaving the basic groups of the diamino-acids unneutralized. They say:

"In order to obtain neutral reacting products one must assume either that some unions occur in which more basic than acid groups have disappeared, or that nitrogen-free acids occur together with the amino-acids. It is not clear how, in the first case, the bindings can be represented. If unions of this kind occur a neutral body on hydrolysis must yield a basic reacting mixture of amino-acids which, after digestion with trypsin and erepsin, must be noticeable. . . . We, therefore, do not believe in the existence of such bindings in the protein molecule. . . . The second assumption, that nitrogen-free acids are present also is not probable, because, in the many investigations known to us which have been made of the composition of the proteins, such acids have never been isolated, with the exception of carbonic acid and very small amounts of methyl sulfuric acid."

Andersen and Roed-Müller then show that no volatile nitrogen-free acid except carbonic is yielded by casein. Believing that these considerations raise a question as to how the ammonia nitrogen is actually bound in the protein molecule, they say: "The assumption of the presence of all the ammonia as equivalent to the monoaminodicarboxylic acids and united with these, is not in harmony with the properties of the proteins." This conclusion of Andersen and Roed-Müller does not have the force that they attribute to it because the products of hydrolysis of proteins form a buffer solution in which an excess of alkali, or acid, would have but little effect in changing the reaction. Andersen and Roed-Müller⁸ believe that the experiments of Skraup and von Hardt-Stremayr,⁹ and also those of Denis¹⁰ indicate that all the ammonia nitrogen cannot be present in amide combination. These investigators state that ammonia is not liberated at a uniform rate when proteins are boiled with strong acid, but that the last part is set free gradually and that the maximum amount is not produced until after the biuret reaction has vanished and the hydrolysis has been completed, or nearly completed.

⁸ Andersen, A. C., and Roed-Müller, R., *Biochem. Z.*, 1915, lxx, 442.

⁹ Skraup, Z. H., and von Hardt-Stremayr, E., *Sitzungsber. k. Akad. Wissensch. Math-naturw. cl. Wien., 2te Abt.*, 1908, cxvii, 25.

¹⁰ Denis, W., *J. Biol. Chem.*, 1910, viii, 432.

Glutamine and asparagine on the other hand yield all their amide nitrogen after a brief treatment with hot dilute acid. They, therefore, consider the possibility of uramino-acids as a source of a part of the ammonia nitrogen.

Experience has convinced us that, at least, in the case of gliadin, or of edestin, all but an insignificant part of the ammonia nitrogen is liberated by boiling for a comparatively short time with very dilute acid, while at the same time only a small part of the peptide bindings are set free. We are also convinced that the slightly higher figures for ammonia, which others have obtained by subjecting proteins to severe treatment with acids, compared with the lower figures obtained after a milder treatment are to be ascribed to secondary decomposition of some of the amino-acids.

Thus we have found that boiling gliadin with 1 per cent HCl for 2 hours converted 23.6 per cent of the gliadin nitrogen into ammonia and only 3.7 per cent into free amino nitrogen, while after 5 hours these figures were 24.2 and 9.0 per cent, respectively. The average maximum yield of ammonia after boiling gliadin with 20 per cent HCl for 24 hours is very little greater; namely, 24.4 per cent of the total nitrogen. These figures show that 97 per cent of the ammonia nitrogen is liberated before more than a small proportion of the peptide bindings has been broken.

Uramino-acids are converted into hydantoins by boiling with dilute acids and yield ammonia only when boiled with strong acids for a long time. The uramino group,^{8,11} as a source of more than a very small part of the ammonia nitrogen of gliadin, is thus excluded.

SUMMARY.

When gliadin is boiled with dilute acid a degree of acidity is developed which is closely proportional to the amount of ammonia, thus indicating that ammonia originates from R-CONH₂ groups.

Since very nearly as much ammonia is produced by boiling for a short time with 1 per cent HCl as by boiling for 24 hours with 20 per cent HCl the presence of more than extremely small amounts of uramino groups, R-CH-NH-CO-NH₂, is excluded.

¹¹ Cf. also Lippich, F., *Z. physiol. Chem.*, 1914, xc, 441.

METHODS USED IN DETERMINING THE ELECTRIC CONDUCTIVITY OF SOLUTIONS.*

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In making a study of the permeability of bacterial membranes it was thought advisable to look into the principles of the methods used in determining electric conductivity of solutions, since they applied to the study of suspensions of bacteria. The method generally used requires an alternating current, Wheatstone bridge, and telephone for detecting the current. The solution is placed in a conductivity cell containing two metallic plates or electrodes. Since the electrodes are usually made of platinum, and platinum salts are absent from the solution, polarization occurs at the electrodes and no considerable current can pass in one direction without a potential difference across the phase boundary equal to the decomposition potential of the water or salts composing the solution. Since the decomposition potential of water is 1.7 volts and potentials of various salts fluctuate around this figure, a counter E. M. F. of about 1 or 2 volts is added to the passive resistance of the solution and prevents the estimation of the latter. In order to obtain correct results, no current should be allowed to pass between the electrodes and the solution. The electrode surface and solution surface constitute an electric condenser of enormous capacity, since the capacity of a condenser varies inversely with the distance between the plates and this distance is very small, being the thickness of the electric double layer at the metal-water surface. By increasing the frequency of the alternating current and increasing the surface area of the electrodes a point may be reached at which the impedance caused

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by the phase boundary is so small as not to interfere with results of considerable accuracy. Alternating currents of high frequency may be produced by means of Vreeland oscillators, and by vacuum tube oscillators as used in wireless transmission. The electrode surface may be increased by enlarging the electrode or roughening it. An extremely rough electrode surface may be obtained by rapid electroplating in a solution of platinic chloride containing a trace of basic lead acetate. This platinized surface is so rough that it does not reflect light into the eye and hence appears black. Platinized electrodes have an enormous capacity when freshly prepared, but the capacity may decrease with use. This decrease is probably due to the interposition of a poorly conducting layer between the metal and the solution due to adsorption of colloids, or to stoppage of the pores in the surface, thus decreasing the area acting as a condenser. The capacity of a dirty electrode may sometimes be restored by cleaning it with a saturated solution of a bichromate in concentrated sulfuric acid. If this fails, the electrode must be platinized again.

In some of our experiments the electrodes decreased in capacity while the bacterial suspension remained in the conductivity vessel, and cleaning or platinizing of the electrode would necessitate complete change in experimental procedure. In such cases, not only is the impedance greater than the resistance that it is desired to measure, but a tone silence in the telephone cannot be obtained owing to the fact that the current is not in phase with the voltage across the conductivity cell. In recent years, a compensation method for obtaining a tone silence or sharp tone minimum in the telephone has been widely advocated in this country. The method usually consists in the placing of a variable condenser in parallel with the resistance box in the ordinary Wheatstone bridge apparatus (in which the two other resistances are represented on a meter wire with sliding contact). This method enables the operator to obtain a sharp tone-minimum and express his results in figures with five decimal places. It is one of the objects of this communication, however, to emphasize that such figures may be incorrect in the second place.

Our experiments have been made with frequencies varying continuously from 60 to 500,000 cycles per second produced by a Vreeland oscillator and a vacuum tube oscillator made of a West-

ern Electric, VT 2, bulb. At radio-frequencies, we have had to simplify the apparatus in order to obtain currents in phase with the voltage and have had to eliminate much of the Wheatstone bridge apparatus. Furthermore, we used a crystal detector and galvanometer and have never achieved the accuracy possible with the lower frequencies and telephone. This paper will be confined, therefore, to work with the Vreeland oscillator and telephone receiver.

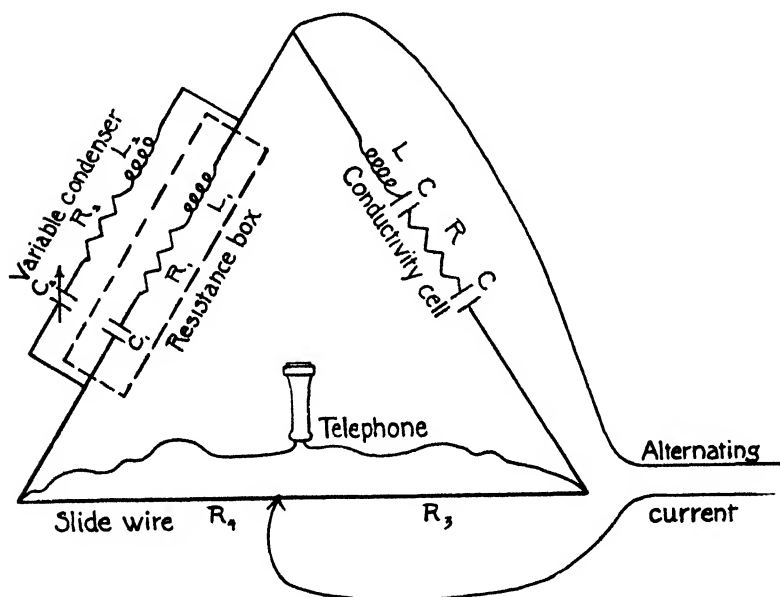


FIG. 1.

Our Wheatstone bridge is diagramed in Fig. 1, in which resistance is denoted by R , capacity by C , and inductance by L . In the conductivity cell, the resistance, R , is the solution; the total capacity is one-half the capacity of one electrode surface, C ; and the inductance, L , is in the connecting wires. By straightening these wires, the inductance may be reduced to a small figure. The resistance box has a variable resistance, R_1 , a small capacity in parallel but an infinite capacity in series, C_1 , and a small inductance, L_1 . In parallel with the resistance box is a variable

condenser with variable capacity, C_2 , small resistance, R_2 , and small inductance, L_2 . In the cell arm of the bridge, given the resistance in ohms, the capacity in farads, and the inductance in henries, the impedance, Z , to the flow of alternating current of frequency, f , is

$$Z = \sqrt{R^2 + \left(2\pi fL - \frac{1}{2\pi fC}\right)^2}$$

In the resistance box arm of the bridge the calculation is a little more complicated and will be given in greater detail.

The impedance, Z , may be resolved into two components, the resistance, R , and the reactance, X , such that

$$Z = \sqrt{R^2 + X^2}$$

where the reactance

$$X = 2\pi fL - \frac{1}{2\pi fC}$$

The admittance, Y , is the reciprocal of the impedance, Z ; the conductance, G , is the reciprocal of the resistance, R ; and the susceptance, B , is the reciprocal of the reactance, X , and

$$Y = \sqrt{G^2 + B^2}$$

or for the parallel circuit

$$Z = \frac{1}{Y} = \frac{1}{\sqrt{G^2 + B^2}} = \frac{1}{\sqrt{\left(\frac{R_1}{Z_1^2} + \frac{R_2}{Z_2^2}\right)^2 + \left(\frac{X_1}{Z_1^2} + \frac{X_2}{Z_2^2}\right)^2}}$$

But if the inductance and capacity of the resistance box are disregarded as well as the resistance and inductance of the variable condenser, and if the latter is so constructed to be of negligible dielectric loss, the equation may be simplified and reduced to the following.

$$Z = \frac{1}{\sqrt{\frac{1}{R_1^2} + (-2\pi fC_2)^2}}$$

In case the self-inductance of the conductivity cell is negligible, the resistance, R , of the solution may be found from the following proportion.

$$\sqrt{R^2 + \left(-\frac{1}{2\pi fC}\right)^2} : \frac{1}{\sqrt{\frac{1}{R_1^2} + (-2\pi fC_2)^2}} = R_3 : R_4$$

Example.—The following determination was made on 1 per cent NaCl in water in a conductivity cell containing bright gold electrodes 25 mm. square, at 25°. $R_1 = 20$ ohms, $C_2 = 1.06 \times 10^{-6}f$, $R_3 = 478$ and $R_4 = 522$, and $f = 5,000$. The impedance of the arm of the bridge containing resistance box and variable condenser was

$$\frac{1}{\sqrt{\frac{1}{20^2} + (6.2832 \times 5,000 \times 1.06 \times 10^{-6})^2}} = 16.67 \text{ ohms}$$

and the impedance of the cell: $16.67 = 478 : 522$, therefore the impedance of the cell = 15.28.

Since the difference in phase between the current and voltage is the same in the two arms of the bridge, the following ratio holds.

$$\frac{1}{R_1} : \frac{1}{16.67} = R : 15.28$$

therefore $R = 16.67 \times 15.28 \div 20 = 12.73$ ohms

It should be emphasized that if the usual method of disregarding the reactance of the bridge is followed the calculation is

$$R : 20 = 478 : 522$$

therefore

$$R = 18.314$$

in other words, the resistance of the solution is 12.73 ohms, whereas the uncorrected calculation gives 18.314 ohms, or 28 per cent too high a value.

A Method of Procuring Sharp Tone-Minimum with Bright Electrodes without the Necessity of Complicated Calculations.

If the variable condenser, $C_2R_2L_2$, is removed from the Wheatstone bridge, a tone-minimum of great sharpness may be secured with the aid of a variable inductor, L , in series with the con-

ductivity cell. With bright electrodes, 25 mm. square, we found the General Radio Variometer 107 C, with a range of about 0.02 to 0.5 millihenries sufficient, and the cost was a small fraction of that of the variable condenser necessitated by the previous method. Since there is loss of power due to dielectric hysteresis in a paraffined paper condenser, a high grade condenser of maximum capacity of 10 microfarads had to be used in the previous method and hence the high cost.

If the reactance of the resistance box is negligible, the reactance of the conductivity cell plus variometer is zero when the variometer is adjusted for sharp tone silence, as follows:

$$\text{Reactance} = 2\pi fL - \frac{1}{2\pi fC}$$

and tone-minimum is not secured until the inductance, L , is so adjusted that it compensates the capacity, C , of the cell so that the reactance becomes zero.

With the elimination of the reactance from the equation, the calculation involves only the resistances in the four arms of the bridge and the subtraction of the resistance of the variometer from the resistance of the arm of the bridge containing it, in order to obtain the resistance of the conductivity cell. The variometer is made of two coils rotating on an axis in the plane of the coils, and hence the current passes through the whole length of wire no matter what the setting for inductance. Therefore, the resistance of the variometer does not change except at frequencies high enough to produce skin effect. The resistance of the variometer may be determined once for all. Its resistance was 1.095 with coils connected in series and 0.2855 with coils connected in parallel for low inductance.

The use of the variometer eliminates the necessity of platinizing the electrodes, and allows the use of smaller electrodes, thus adapting the conductivity method to a wider range of usefulness in biochemistry. Sufficient current must be used in order to work the telephone diaphragm, but, if the conductivity of the solution is high enough, very small electrodes may be used without danger of reaching current saturation. An inductance has been used by Taylor and Acree,¹ but their results were reduced to infinite frequency.

¹ Taylor, W. A., and Acree, S. F., *J. Am. Chem. Soc.*, 1916, xxxviii, 2403.

RATE OF HYDROLYSIS OF PHOSPHORIC ESTERS OF SUGAR DERIVATIVES.

FIRST PAPER.

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A number of the components of the tissues contain in their molecules either phosphoric or sulfuric acid. The phosphoric acid radicle is contained in the mono- and polynucleotides, and the sulfuric acid radicle in chondroitin- and mucoitin-sulfuric acids. In all these compounds the acid radicle is linked in ester form to either a carbohydrate or a polyhydric alcohol. On long acquaintance with substances of this character, one comes to realize that the inorganic radicle is linked in different substances of the same group with different degrees of firmness. Thus, for instance, in inosinic and uridinphosphoric acids on one hand, and in guanylic on the other; in chondroitin-sulfuric on one hand, and in mucoitin sulfuric on the other, the organic acids display different degrees of resistance towards hydrolytic agents.

In compounds such as the ribose nucleotides, two components of the molecule, the sugar, and the inorganic acid, remain constant, and only the third component is variable. It is evident that the firmness of the union between the acid and the rest of the molecule may be conditioned by two factors: the character of the base, and the position of the acid radicle on the sugar molecule.

There exists no systematic study of the rate of hydrolysis of ester form derivatives of sugars which have only one point of difference; namely, that of the allocation of the acid radicle. However, in the preparative work on sugar derivatives by Fischer¹ and his students, and by Irvine² and his students, one

¹ Fischer, E., and Noth, H., *Ber. chem. Ges.*, 1918, li, 321.

² Irvine, J. C., and Scott, J. P., *J. Chem. Soc.*, 1913, ciii, 575.

finds abundant evidence that such differences in the rate of hydrolysis exist.

A more detailed as well as a more systematic investigation of this problem is much desired not only for purely academic considerations, but also for what, in a way, may be regarded as practical or applied reasons.

It is a difficult task to determine the allocation of an acyl group on the sugar molecule by direct chemical method. On few occasions the method was successful, and only then when the substitution took place on the primary alcoholic group. When any of the secondary alcoholic groups are substituted the allocation of the substituting group has thus far not been successful. As yet the present work does not embrace a sufficiently large number of esters, and is offered in its present form because one of the authors is compelled to discontinue his cooperation.

The substances³ employed in this work were phosphoric esters of: (1) α -methylglucoside; (2) β -, γ -, ϵ -trimethyl methylglucoside; (3) α -, β -, γ -, ϵ -diacetone glucose; (4) α -, β -monoacetone glucose; (5) a phosphoric ester of the same sugar derivative as in (4), but differing from the substance (4) by the position of the phosphoric acid radicle; (6) ζ -benzoyl- α - β -monoacetone glucose.

In the first, the position of the phosphoric acid radicle is not established, and the interest attached to the substance is due primarily to the fact that the sugar radicle in it is non-substituted. In the following two substances, namely β -, γ -, ϵ -trimethyl methylglucoside and diacetone glucose, the phosphoric acid radicle is attached to the same carbon atom, and hence the two substances differ in the nature and in the molecular weight of the substituting groups. Differences in the rate of hydrolysis of these two substances should be attributed to the influence of these groups.

The fourth substance differed from the fifth in the method of preparation. Whereas the latter was obtained by the action of phosphorous oxychloride on monoacetone glucose, the former is formed as a by-product by the action of phosphorous oxychloride on diacetone glucose. Apparently in the former substance the phosphoric acid radicle was linked to the primary alcoholic group,

³The preparation of these substances will be described in a subsequent paper by P. A. Levene and G. M. Meyer.

whereas in the latter it was linked to one of the secondary alcoholic groups.

The sixth substance, ζ -benzoyl- α - β -monoacetone glucosidophosphoric acid, differs from the preceding two by the position of the phosphoric acid radicle, by the number of the substituting groups, and by the difference in character of one of the substituting groups.

The hydrolysis of these substances was carried out in approximately equivalent concentration, which was in the neighborhood of 10 per cent. As catalytic agent 0.1 N sulfuric acid was employed. The temperature of hydrolysis was 100°C.

As was anticipated, the rate of hydrolysis followed the monomolecular law. The constants of hydrolysis $K = \frac{1}{t} \log \frac{a}{a-x}$ were as follows:

$$K_1 = 22 (10^{-3})$$

$$K_2 = 43 (10^{-3})$$

$$K_3 = 56 (10^{-3})$$

$$K_4 = 44 (10^{-3})$$

$$K_5 = 58 (10^{-3})$$

$$K_6 = 18 (10^{-3})$$

(The subscripts indicate the substances in the order of their tabulation.)

Thus in this series of substances apparently both the position of the phosphoric acid radicle and the nature of the substituting groups exert an influence on the stability of the phosphoric ester linking.

On the other hand, the constants of hydrolysis of the sugar derivatives which differ from one another only in point of position of the acid radicle, as Substances 4 and 5, are determined by the position of the inorganic radicle.

It was expected that the position of the phosphoric acid radicle would play the determining part in the rate of hydrolysis. This expectation has not materialized, and it will therefore be necessary to prepare such phosphoric esters of glucose or of methylglucoside which will have the inorganic radicle in a known position, and which will be free from other substituting groups.

It is planned to continue the work in this direction in this laboratory.

EXPERIMENTAL.

α-Methylglucosidophosphoric Acid.—11.644 gm. of barium methylglucosidophosphate were ground up with a little water, 49.2 cc. of $N H_2SO_4$ were added, and the volume was made up to 100 cc. The solution was filtered from the barium sulfate without further addition of water.

The concentration of methylglucosidophosphoric acid was established by a polariscopic determination; 5 cc. of the solution contained 0.450 gm. of methylglucosidophosphoric acid, representing 0.0509 gm. of P.

5 cc. of this solution were pipetted into glass tubes together with 5 cc. of 0.2 $N H_2SO_4$. The tubes were sealed and heated in an oil bath at 100°C. for various intervals as indicated in the tables. After cooling, the contents of each tube were made up to 100 cc. and the phosphorous was determined as magnesium pyrophosphate on 40 cc. of this solution.

The results are tabulated in Tables I, Ia, II, and IIa.

β-γ-ε-Trimethyl Methylglucosido-ξ-Phosphoric Acid.—13.0785 gm. of the barium salt were ground up in a little water, the barium was precipitated by 42.7 cc. of $N H_2SO_4$, and the solution made up to 100 cc. 5 cc. of this solution contained 0.45 gm. of trimethyl methylglucosidophosphoric acid, determined polarimetrically, equivalent to 0.0441 gm. of phosphorus.

5 cc. of the filtrate were heated in sealed tubes with 5 cc. of 0.2 $N H_2SO_4$ for various periods at 100° and the phosphorus was determined as magnesium pyrophosphate.

The results are tabulated in Tables III, IIIa, IV, and IVa.

α-β-γ-ε-Diacetone Glucosido-ξ-Phosphoric Acid.—10.1805 gm. of the barium salt were dissolved in a small volume of water and made up to 75 cc. 5 cc. of this solution, containing 0.450 gm. of diacetone glucoside phosphoric acid, equivalent to 0.041 gm. of phosphorus, were pipetted into glass tubes together with 3.3 cc. of $N H_2SO_4$ and 1.7 cc. of water. The tubes were sealed and heated at 100° for various intervals.

The results are tabulated in Tables V and Va.

α-β-Monoacetone Glucosido-ξ-Phosphoric Acid (from Diacetone Glucose).—7.5617 gm. of the barium salt of this substance were dissolved in a small volume of warm water and made up to 50 cc.

Of this solution 3 cc., equivalent to 0.029 gm. of P, were pipetted into glass tubes together with 2.27 cc. of $N H_2SO_4$ and 0.73 cc. of water and sealed. The tubes were heated at 100° for various intervals.

The results are tabulated in Tables VI and VIa.

α - β -Monoacetone Glucosidophosphoric Acid (from Monoacetone Glucose).—5.876 gm. of the barium salt of the substance were dissolved in a small quantity of warm water and made up to 40 cc. 3 cc. of this solution, equivalent to 0.028 gm. of P, together with 2.29 cc. of $N H_2SO_4$ and 0.71 cc. of water were heated in sealed tubes for various intervals.

The results are tabulated in Tables VII and VIIa.

ζ -Benzoyl- α - β -Monoacetone Glucosidophosphoric Acid.—8.4285 gm. of the barium salt of the substance were rubbed up with a small volume of warm water, made up to 75 cc., and filtered. 5 cc. of the filtrate, equivalent to 0.035 gm. of P, together with 2.97 cc. of $N H_2SO_4$ and 2.03 cc. of water were heated in sealed tubes for various intervals.

The results are tabulated in Tables VIII and VIIIa.

TABLE I.
α-Methylglucosidophosphoric Acid.

Time.	Mg ₃ P ₂ O ₇	Average.	P in Mg ₃ P ₂ O ₇	P in free acid.	P in total P.
hrs.	gm.	gm.	gm.	per cent	per cent
1	0.0015	0.0016	0.0004	0.24	2.16
	0.0016				
	0.0017	0.0017	0.0005	0.27	2.36
	0.0016				
2	0.0043	0.0044	0.0012	0.69	6.09
	0.0045				
	0.0044	0.0045	0.0013	0.69	6.09
	0.0045				
4	0.0081	0.0082	0.0023	1.27	11.20
	0.0083				
	0.0085	0.0087	0.0024	1.34	11.98
	0.0088				
8	0.0175	0.0173	0.0048	2.69	23.77
	0.0171				
	0.0177	0.0178	0.0050	2.76	24.36
	0.0178				
16	0.0296	0.0294	0.0082	4.56	40.27
	0.0292				
	0.0304	0.0299	0.0083	4.62	40.86
	0.0294				
24	0.0394	0.0395	0.0110	6.11	54.03
	0.0396				
	0.0396	0.0397	0.0111	6.11	54.03
	0.0398				

TABLE II.
α-Methylglucosidophosphoric Acid.

Time.	Mg ₂ P ₂ O ₇	Average.	P in Mg ₂ P ₂ O ₇	P in free acid.	P in total P.
hrs.	gm.	gm.	gm.	per cent	per cent
1	0.0014	0.0015	0.0004	0.24	2.16
	0.0016				
	0.0018	0.0017	0.0005	0.27	2.36
	0.0016				
2	0.0044	0.0043	0.0012	0.67	5.89
	0.0042				
	0.0042	0.0044	0.0012	0.69	6.09
	0.0046				
4	0.0082	0.0082	0.0023	1.27	11.20
	0.0081				
	0.0087	0.0087	0.0024	1.33	11.79
	0.0086				
8	0.0170	0.0170	0.0047	2.62	23.18
	0.0170				
	0.0170	0.0170	0.0047	2.62	23.18
	0.0170				
16	0.0304	0.0306	0.0085	4.78	42.24
	0.0308				
	0.0314	0.0315	0.0088	4.89	43.22
	0.0315				
24	0.0409	0.0408	0.0114	6.31	55.78
	0.0406				
	0.0417	0.0418	0.0116	6.47	57.17
	0.0418				
32	0.0504	0.0504	0.0140	7.80	68.96
	0.0504				
	0.0500	0.0501	0.0140	7.76	68.56
	0.0502				

TABLE III.
β-γ-ε-Trimethyl Methylglucosido-ξ-Phosphoric Acid.

Time.	Mg ₃ P ₂ O ₇	Average.	P in Mg ₃ P ₂ O ₇	P in free acid.	P in total P.
<i>hrs.</i>	<i>gm.</i>	<i>gm.</i>	<i>gm</i>	<i>per cent</i>	<i>per cent</i>
1	0.0025	0.0025	0.0007	0.38	3.83
	0.0025				
	0.0026				
	0.0026				
2	0.0071	0.0070	0.0020	1.09	11.04
	0.0069				
	0.0060				
	0.0068				
4	0.0124	0.0125	0.0035	1.93	19.60
	0.0125				
	0.0129				
	0.0120				
8	0.0247	0.0247	0.0069	3.82	38.74
	0.0247				
	0.0242				
	0.0240				
16	0.0403	0.0403	0.0112	6.22	63.06
	0.0402				
	0.0410				
	0.0412				
24	0.0527	0.0527	0.0147	8.16	82.66
	0.0526				
	0.0524				
	0.0527				

TABLE IV.
 β - γ - ϵ -Trimethyl Methylglucosido- ζ -Phosphoric Acid.

Time.	Mg ₂ P ₂ O ₇	Average.	P in Mg ₂ P ₂ O ₇	P in free acid.	P in total P.
<i>hrs.</i>	<i>gm.</i>	<i>gm.</i>	<i>gm</i>	<i>per cent</i>	<i>per cent</i>
1	0 0028	0.0027	0 0008	0.42	4 24
	0 0026				
	0 0026	0 0026	0.0007	0.40	4 08
	0 0025				
2	0 0071	0 0073	0.0020	1.13	11 46
	0 0074				
	0 0068	0 0069	0 0019	1 07	10 83
	0.0070				
4	0.0130	0 0130	0 0036	2.01	20 40
	0 0130				
	0 0125	0.0128	0.0036	1.98	20 09
	0 0130				
8	0.0245	0.0246	0 0069	3.81	38.60
	0 0246				
	0 0246	0.0245	0 0068	3.79	38.45
	0.0245				
16	0.0388	0.0389	0 0108	6 02	61 04
	0.0390				
	0.0386	0.0388	0.0108	6 00	60.81
	0.0390				
24	0.0496	0.0494	0.0138	7.64	77.48
	0.0492				
	0.0492	0 0493	0 0137	7.62	77.25
	0.0494				

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TABLE V.
α-β-γ-ε-Diacetone Glucoside-ζ-Phosphoric Acid.

Time.	Mg ₃ P ₂ O ₇	Average.	P in Mg ₃ P ₂ O ₇	P in free acid.	P in total P.
<i>hrs.</i>	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>	<i>per cent</i>	<i>per cent</i>
1	0.0040	0.0040	0.0011	0.62	6.80
	0.0040				
	0.0037	0.0039	0.0011	0.62	6.80
	0.0040				
2	0.0090	0.0088	0.0025	1.36	14.95
	0.0085				
	0.0091	0.0091	0.0025	1.41	15.46
	0.0090				
4	0.0159	0.0157	0.0044	2.43	26.68
	0.0157				
	0.0154	0.0156	0.0043	2.42	26.51
	0.0158				
8	0.0262	0.0262	0.0073	4.06	44.52
	0.0262				
	0.0262	0.0262	0.0073	4.06	44.52
	0.0262				
16	0.0419	0.0429	0.0117	6.64	72.90
	0.0438				
	0.0419	0.0419	0.0117	6.49	71.20
	0.0394				
24	0.0525	0.0525	0.0146	8.13	89.22
	0.0525				
	0.0525	0.0525	0.0146	8.13	89.22
	0.0525				

TABLE VI.

 α - β -Monoacetone Glucosido- ζ -Phosphoric Acid (from Diacetone Glucose).

Time.	Mg ₂ P ₂ O ₇	Average.	P in Mg ₂ P ₂ O ₇	P in free acid.	P in total P.
hrs.	gm.	gm.	gm.	per cent	per cent
1	0.0050	0.0049	0.0014	0.78	7.56
	0.0047				
	0.0048	0.0048	0.0014	0.78	7.56
	0.0047				
2	0.0103	0.0100	0.0028	1.56	15.12
	0.0097				
	0.0100	0.0100	0.0028	1.56	15.12
	0.0100				
4	0.0183	0.0182	0.0051	2.84	27.65
	0.0180				
	0.0175	0.0174	0.0048	2.67	25.92
	0.0173				
8	0.0323	0.0323	0.0090	5.00	48.60
	0.0323				
	0.0320	0.0320	0.0089	4.96	48.16
	0.0320				
16	0.0483	0.0483	0.0135	7.51	73.00
	0.0483				
	.....	0.0483	0.0135	7.51	73.00
	0.0483				
24	0.0570	0.0570	0.0159	8.84	85.96
	0.0570				
	0.0570	0.0570	0.0159	8.84	85.96
	0.0570				

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TABLE VII.

α - β -Monoacetone Glucosidophosphoric Acid (from Monoacetone Glucose).

Time.	Mg ₂ P ₂ O ₇	Average.	P in Mg ₂ P ₂ O ₇	P in free acid.	P in total P.
hrs.	gm.	gm.	gm	per cent	per cent
1	0.0033	0.0036	0.0010	0.55	5.40
	0.0038				
	0.0035	0.0036	0.0010	0.55	5.40
	0.0037				
2	0.0073	0.0077	0.0021	1.18	11.45
	0.0080				
	0.0075	0.0076	0.0021	1.18	11.45
	0.0077				
4	0.0150	0.0152	0.0042	2.33	22.68
	0.0153				
	0.0143	0.0144	0.0040	2.22	21.60
	0.0145				
8	0.0260	0.0265	0.0074	4.11	39.96
	0.0270				
	0.0268	0.0265	0.0074	4.11	39.96
	0.0261				
16	0.0405	0.0407	0.0113	6.29	61.12
	0.0408				
	0.0403	0.0403	0.0112	6.22	60.47
	0.0403				
24	0.0511	0.0511	0.0142	7.89	76.67
	0.0511				
	0.0508	0.0509	0.0142	7.89	76.67
	0.0510				

TABLE VIII.

ξ-Benzoyl-α-β-Monoacetone Glucosidophosphoric Acid.

Time.	Mg ₂ P ₂ O ₇	Average.	P in Mg ₂ P ₂ O ₇	P in free acid.	P in total P.
<i>hrs</i>	<i>gm</i>	<i>gm.</i>	<i>gm.</i>	<i>per cent</i>	<i>per cent</i>
1	0.0012	0.0012	0.0003	0.19	2.42
	0.0012				
	0.0012	0.0012	0.0003	0.19	2.42
	0.0012				
2	0.0022	0.0022	0.0006	3.40	4.42
	0.0022				
	0.0021	0.0021	0.0006	3.24	4.42
	0.0021				
4	0.0048	0.0048	0.0013	7.42	9.65
	0.0048				
	0.0048	0.0048	0.0013	7.42	9.65
	0.0048				
8	0.0094	0.0094	0.0026	14.56	18.93
	0.0094				
	0.0094	0.0094	0.0026	14.56	18.93
	0.0094				
16	0.0174	0.0174	0.0048	26.93	35.03
	0.0173				
	0.0174	0.0174	0.0048	26.93	35.03
	0.0174				
24	0.0223	0.0223	0.0062	34.53	44.92
	0.0223				
	0.0223	0.0223	0.0062	34.53	44.92
	0.0223				

*Velocity Constants.*TABLE Ia.
α-Methylglucosidophosphoric Acid.

<i>t</i>	Mg ₃ P ₂ O ₇ (<i>x</i>)	<i>a - x</i>	$\frac{1}{t} \log \frac{a}{a-x}$
<i>min.</i>	<i>gm.</i>		
0			
60	0.0017	0.0714	0.00017
120	0.0045	0.0686	0.00023
240	0.0085	0.0646	0.00022
480	0.0176	0.0555	0.00025
960	0.0297	0.0434	0.00023
1,440	0.0396	0.0335	0.00023
	<i>a</i> = 0.0731		
Average.....			0.00022

TABLE IIa.
α-Methylglucosidophosphoric Acid.

<i>t</i>	Mg ₃ P ₂ O ₇ (<i>x</i>)	<i>a - x</i>	$\frac{1}{t} \log \frac{a}{a-x}$
<i>min.</i>	<i>gm.</i>		
0			
60	0.0016	0.0715	0.00016
120	0.0044	0.0687	0.00022
240	0.0085	0.0646	0.00022
480	0.0170	0.0561	0.00023
960	0.0311	0.0420	0.00025
1,440	0.0413	0.0318	0.00025
1,920	0.0503	0.0228	0.00026
	<i>a</i> = 0.0731		
Average.....			0.00022

TABLE IIIa.

β-γ-ε-Trimethyl Methylglucosido-ξ-Phosphoric Acid.

<i>t</i>	Mg ₂ P ₂ O ₇ (<i>x</i>)	<i>a</i> - <i>x</i>	$\frac{1}{t} \log \frac{a}{a-x}$
<i>min.</i>	<i>gm.</i>		
0			
60	0.0026	0.0608	0.00030
120	0.0069	0.0565	0.00042
240	0.0125	0.0509	0.00040
480	0.0244	0.0390	0.00044
960	0.0407	0.0227	0.00046
1,440	0.0527	0.0107	0.00053
	<i>a</i> = 0.0634		
Average.....			0.00044

TABLE IVa.

β-γ-ε-Trimethyl Methylglucosido-ξ-Phosphoric Acid.

<i>t</i>	Mg ₂ P ₂ O ₇ (<i>x</i>)	<i>a</i> - <i>x</i>	$\frac{1}{t} \log \frac{a}{a-x}$
<i>min.</i>	<i>gm</i>		
0			
60	0.0027	0.0607	0.00032
120	0.0071	0.0563	0.00043
240	0.0129	0.0505	0.00041
480	0.0246	0.0388	0.00044
960	0.0389	0.0245	0.00043
1,440	0.0494	0.0140	0.00045
	<i>a</i> = 0.0634		
Average.....			0.00041

TABLE Va.

α-β-γ-ε-Diacetone Glucosido-ξ-Phosphoric Acid.

<i>t</i>	Mg ₂ P ₂ O ₇ (<i>x</i>)	<i>a</i> - <i>x</i>	$\frac{1}{t} \log \frac{a}{a-x}$
<i>min.</i>	<i>gm.</i>		
0			
60	0.0040	0.0549	0.00050
120	0.0090	0.0499	0.00060
240	0.0157	0.0432	0.00056
480	0.0262	0.0327	0.00053
960	0.0424	0.0165	0.00058
1,440	0.0525	0.0064	0.00067
	<i>a</i> = 0.0589		
Average.....			0.00056

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TABLE VIa.

α - β -Monoacetone Glucose- ζ -Phosphoric Acid (from Diacetone Glucose).

<i>t</i>	$Mg_2P_2O_7(x)$	$a - x$	$\frac{1}{t} \log \frac{a}{a-x}$
<i>min.</i>	<i>gm.</i>		
0			
60	0.0049	0.06168	0.000553
120	0.0100	0.05658	0.000588
240	0.0178	0.04878	0.000563
480	0.0322	0.03438	0.000598
960	0.0483	0.01828	0.000585
1,440	0.0570	0.00958	0.000585
	$a = 0.06658$		
Average.....			0.000579

TABLE VIIa.

α - β -Monoacetone Glucosidophosphoric Acid (from Monoacetone Glucose).

<i>t</i>	$Mg_2P_2O_7(x)$	$a - x$	$\frac{1}{t} \log \frac{a}{a-x}$
<i>min.</i>	<i>gm.</i>		
0			
60	0.0036	0.06298	0.000400
120	0.0077	0.05888	0.000445
240	0.0148	0.05178	0.000455
480	0.0265	0.04008	0.000459
960	0.0405	0.02608	0.000423
1,440	0.0510	0.01558	0.000438
	$a = 0.06658$		
Average.....			0.000437

TABLE VIHa.

ζ -Benzoyl- α - β -Monoacetone Glucosidophosphoric Acid.

<i>t</i>	$Mg_2P_2O_7(x)$	$a - x$	$\frac{1}{t} \log \frac{a}{a-x}$
<i>min.</i>	<i>gm.</i>		
0			
60	0.0012	0.0485	0.000177
120	0.0022	0.0475	0.000164
240	0.0048	0.0449	0.000183
480	0.0094	0.0403	0.000189
960	0.0174	0.0323	0.000194
1,440	0.0223	0.0274	0.000180
	$a = 0.0497$		
Average.....			0.000181

HYDROLYSIS OF NUCLEOTIDES.

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Early in the work on nucleotides it was observed that individual members of this group differed in their resistance to the action of hydrolytic agents. Owing to this peculiarity, Levene and Mandel obtained on hydrolysis of thymus nucleic acid a mononucleotide: thymidinphosphoric acid.¹ Later, Levene, and Levene and Jacobs² prepared the pyrimidin nucleotides of yeast nucleic acid and Levene and Jacobs,³ on hydrolysis of thymus nucleic acid, prepared hexocytidin- and hexothymidindiphosphoric acids. Jones⁴ and his coworkers furnished further observations demonstrating this peculiarity of different nucleotides.

The structural details of the molecule which are responsible for this difference in the behavior of the individual mononucleotides are as yet unknown.

Referring only to the ribose nucleotides, the observations are as follows: Inosinic, uridinphosphoric, and cytidinphosphoric acids demonstrated a higher resistance, whereas adenosinphosphoric and guanosinphosphoric acids possess a lower resistance towards hydrolytic agents.

It is certain that all these nucleotides differ from one another in the nature of the base, but it is also possible that they differ in the position of the phosphoric acid radicle on the carbohydrate.

In only one of these nucleotides, in inosinic acid, is the position of the phosphoric acid known; namely, it is linked to the fifth carbon atom. Whether the stability of this substance is condi-

¹ Levene, P. A., and Mandel, J. A., *Ber. chem. Ges.*, 1908, xli, 1905.

² Levene, P. A., *Biochem. Z.*, 1909, xvii, 120. Levene, P. A., and Jacobs, W., *Ber. chem. Ges.*, 1911, xlv, 1027.

³ Levene, P. A., and Jacobs, W., *J. Biol. Chem.*, 1912, xii, 411.

⁴ Jones, W., and Read, B. E., *J. Biol. Chem.*, 1917, xxix, 123.

tioned by the position of the phosphoric acid radicle cannot as yet be stated. There are indications that this may be so, since the ribose phosphoric acid obtained from this nucleotide also possesses considerable stability.

The differences in the stability hitherto observed are only of a qualitative nature. However, in order that this property of nucleotides may be made the basis for suggestions regarding their structure, it is necessary to obtain more detailed information concerning the comparative rate of hydrolysis of the various nucleotides.

The substances employed in this investigation were as follows: Yeast nucleic acid (employed in form of its barium salt), inosinic acid (in form of barium salt), uridinphosphoric acid (barium salt), guanylic acid (crystalline nucleotide), adenylic acid (crystalline nucleotide), and hexothymidindiphosphoric acid (barium salt).

These substances were employed in approximately equivalent concentrations, and the hydrolysis was accomplished by 0.1 N sulfuric acid at a temperature of 100°C. It was found by Levene and the writer that consistent results were obtained only when the hydrolysis was carried out in sealed tubes. The rate of hydrolysis followed, as was expected, the monomolecular law and the constant of hydrolysis $K = \frac{1}{t} \log \frac{a}{a-x}$ was as follows:

	$\frac{1}{t} \log \frac{a}{a-x}$
Nucleic acid.....	130 (10^{-2})
Guanosinphosphoric acid.....	177 (10^{-2})
Adenosinphosphoric "	166 (10^{-2})
Uridinphosphoric "	480 (10^{-3})
Inosinic acid.....	470 (10^{-3})
Hexothymidindiphosphoric acid.....	726 (10^{-3})

Thus the velocity constants of the guanosinphosphoric and adenosinphosphoric acids is identical. On the other hand the constants of inosinic and uridinphosphoric are also identical in spite of the fact that their basic component is of a different nature.

EXPERIMENTAL.

Nucleic Acid.—4.1184 gm. of barium nucleate were ground up in a small quantity of water and 16.3 cc. of $N H_2SO_4$, made up to 30 cc., and filtered. 5 cc. of this solution by Kjeldahl determination contained 0.4184 gm. of nucleic acid equivalent to 0.0397 gm. of phosphorus.

5 cc. of this solution were hydrolyzed with 5 cc. of 0.2 $N H_2SO_4$ in sealed tubes at 100° for various intervals. The phosphorus was estimated as magnesium pyrophosphate. The results are tabulated in Tables I and 1a.

In Series 2 and 3, 0.5607 gm. of barium nucleate was weighed off for each tube, equivalent to 0.450 gm. of nucleic acid, and this was hydrolyzed with 1.61 cc. of $N H_2SO_4$, and 3.39 cc. of water. The contents of these tubes after heating were treated as previously described. The results are tabulated in Tables II, IIa, III, and IIIa.

Guanosinphosphoric Acid.—6.75 gm. of guanylic acid were dissolved in a small quantity of warm water and made up to 75 cc. By analysis of a sample of this material each 5 cc. of the above solution contained 0.4321 gm. of guanylic acid or an equivalent of 0.0365 gm. of phosphorus. 5 cc. of the guanylic acid solution were hydrolyzed with 5 cc. of 0.2 $N H_2SO_4$ at 100° for various intervals.

The results are tabulated in Tables IV and IVa.

Adenosinphosphoric Acid.—4.733 gm. of adenylic acid are dissolved in a small quantity of warm water and made up to 50 cc.

3 cc. of this solution equivalent to 0.024 gm. of P and 3 cc. of 0.2 $N H_2SO_4$ are hydrolyzed in sealed tubes at 100° for various intervals.

The results are tabulated in Tables V and Va.

Uridinphosphoric Acid.—*Series I.*—10.5404 gm. of barium uridinphosphate were taken up in water and 44.3 cc. of $N H_2SO_4$. The solution was filtered and 5 cc. of the filtrate containing 0.450 gm. of uridinphosphoric acid (Kjeldahl) equivalent to 0.044 gm. of P are hydrolyzed with 5 cc. of 0.2 $N H_2SO_4$ at $100^\circ C.$ for various intervals. The results are tabulated in Tables VI and VIa.

Series II.—9.6435 gm. of barium uridinphosphate are taken up in a little water and 41.6 cc. of $N H_2SO_4$ and further treated

as in the previous series. Results are tabulated in Tables VII and VIIa.

Inosinphosphoric Acid.—11.9936 gm. of barium inosinate were dissolved in a small quantity of water and the barium was precipitated with 38.2 cc. of $N H_2SO_4$. The solution was made up to 75 cc. and filtered. An analysis of the solution (Kjeldahl) showed 5 cc. of solution to contain 0.4453 gm. of inosinic acid equivalent to 0.0397 gm. of phosphorus.

5 cc. of the filtrate were hydrolyzed with 5 cc. of 0.2 $N H_2SO_4$ at $100^\circ C$. for various periods. The results are tabulated in Tables VIII and VIIIa.

Hexothymidindiphosphoric Acid.—9.893 gm. of the barium salt were ground up in a little water and 24.4 cc. of 2 $N H_2SO_4$ and the volume was made up to 50 cc. The solution was filtered and of the filtrate 3 cc. were hydrolyzed with 3 cc. of 0.2 $N H_2SO_4$ at $100^\circ C$. for various intervals. The concentration of the material was established by means of a Kjeldahl nitrogen determination.

3 cc. of the filtrate were equivalent to 0.03947 gm. of phosphorus. The results are tabulated in Tables IX and IXa.

TABLE I.
Nucleic Acid.

Time.	$Mg_2P_2O_7$	Average.	P in $Mg_2P_2O_7$	P in free acid.	P in total P.
hrs.	gm.	gm	gm.	per cent	per cent
1	0.0089	0.0089	0.0025	1.48	15.62
	0.0088				
	0.0090	0.0089	0.0025	1.48	15.62
	0.0088				
4	0.0308	0.0307	0.0086	5.11	53.90
	0.0306				
	0.0309	0.0310	0.0086	5.16	54.41
	0.0310				

TABLE II.
Nucleic Acid.

Time.	Mg ₃ P ₂ O ₇	Average.	P in Mg ₃ P ₂ O ₇	P in free acid.	P in total P.
<i>hrs.</i>	<i>gm</i>	<i>gm.</i>	<i>gm.</i>	<i>per cent</i>	<i>per cent</i>
1	0.0062	0.0062	0.0017	0.94	14.19
	0.0062				
	0.0062	0.0062	0.0017	0.94	14.19
	0.0077				
2	0.0135	0.0135	0.0038	2.11	31.73
	0.0135				
	0.0149	0.0144	0.0040	2.22	33.40
	0.0144				
4	0.0251	0.0250	0.0070	3.89	58.44
	0.0248				
	0.0253	0.0254	0.0071	3.94	59.28
	0.0254				
8	0.0363	0.0360	0.0100	5.56	83.49
	0.0357				
	0.0368	0.0369	0.0103	5.72	85.99
	0.0370				
16	0.0437	0.0436	0.0122	6.78	101.86
	0.0434				
	0.0440	0.0440	0.0123	6.78	101.86
	0.0440				
24	0.0458	0.0459	0.0128	7.11	106.87
	0.0459				
	0.0467	0.0465	0.0130	7.22	108.54
	0.0462				

TABLE III.
Nucleic Acid.

Time.	Mg ₃ P ₂ O ₇	Average.	P in Mg ₃ P ₂ O ₇	P in free acid.	P in total P.
<i>hrs.</i>	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>	<i>per cent</i>	<i>per cent</i>
1	0.0057	0.0058	0.0016	0.89	13.36
	0.0059				
	0.0059	0.0060	0.0017	0.94	14.19
	0.0061				
2	0.0133	0.0135	0.0038	2.11	31.73
	0.0136				
	0.0132	0.0131	0.0037	2.06	30.89
	0.0130				
4	.....	0.0252	0.0070	3.89	58.44
	0.0252				
	0.0254	0.0255	0.0071	3.94	59.28
	0.0256				
8	0.0364	0.0364	0.0101	5.56	83.49
	0.0364				
	0.0366	0.0369	0.0103	5.72	85.99
	0.0372				
16	0.0438	0.0438	0.0122	6.78	101.86
	0.0438				
	0.0436	0.0435	0.0121	6.72	101.02
	0.0434				

TABLE IV.
Guanosinphosphoric Acid.

Time.	Mg ₂ P ₂ O ₇	Average.	P in Mg ₂ P ₂ O ₇	P in free acid	P in total P.
<i>hrs.</i>	<i>gm.</i>	<i>gm</i>	<i>gm.</i>	<i>per cent</i>	<i>per cent</i>
1	0.0098	0.0098	0.0027	1.57	18.43
	0.0098				
	0.0096	0.0096	0.0027	1.55	18.16
	0.0096				
2	0.0200	0.0200	0.0056	3.22	37.67
	0.0201				
	0.0198	0.0198	0.0055	3.19	37.40
				
4	0.0338	0.0341	0.0095	5.51	64.50
	0.0344				
	0.0337	0.0337	0.0094	5.44	63.67
	0.0336				
8	0.0449	0.0450	0.0125	7.27	85.09
	0.0451				
	0.0447	0.0448	0.0125	7.22	84.55
	0.0449				
12	0.0490	0.0488	0.0136	7.87	92.14
	0.0485				
	0.0490	0.0488	0.0136	7.87	92.14
	0.0485				
16	0.0495	0.0496	0.0138	8.01	93.77
	0.0497				
	0.0493	0.0493	0.0137	7.94	92.95
	0.0493				
24	0.0507	0.0507	0.0141	8.19	95.94
	0.0507				
	0.0504	0.0505	0.0141	8.15	95.39
	0.0505				

TABLE V.
Adenosinphosphoric Acid.

Time.	Mg ₃ P ₂ O ₇	Average.	P in Mg ₃ P ₂ O ₇	P in free acid.	P in total P.
<i>hrs.</i>	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>	<i>per cent</i>	<i>per cent</i>
1	0.0110	0.0110	0.0031	1.71	19.15
	0.0110				
	0.0110	0.0110	0.0031	1.71	19.15
	0.0110				
2	0.0223	0.0223	0.0062	3.44	38.56
	0.0223				
	0.0218	0.0224	0.0062	3.44	38.56
	0.0230				
4	0.0372	0.0371	0.0103	5.73	64.18
	0.0370				
	0.0375	0.0375	0.0105	5.84	65.42
	0.0375				
8	0.0475	0.0477	0.0133	7.40	82.84
	0.0478				
	0.0482	0.0479	0.0133	7.40	82.84
	0.0475				
16	0.0537	0.0537	0.0150	8.33	93.28
	0.0537				
	0.0535	0.0536	0.0149	8.29	92.79
	0.0537				
24	0.0540	0.0544	0.0152	8.44	94.53
	0.0547				
	0.0538	0.0543	0.0152	8.44	94.53
	0.0548				

TABLE VI.
Uridinphosphoric Acid.

Time.	Mg ₃ P ₂ O ₇	Average.	P in Mg ₃ P ₂ O ₇	P in free acid.	P in total P.
hrs.	gm.	gm.	gm.	per cent	per cent
1	0.0030	0.0030	0.0008	0.45	4.75
	0.0030				
	0.0029	0.0030	0.0008	0.45	4.75
	0.0030				
2	0.0074	0.0074	0.0021	1.13	11.76
	0.0074				
	.....	0.0074	0.0021	1.13	11.76
	0.0074				
4	0.0120	0.0136	0.0038	2.06	21.49
	0.0136				
	0.0134	0.0136	0.0038	2.06	21.49
	0.0137				
8	0.0257	0.0255	0.0071	3.85	40.27
	0.0253				
	0.0257	0.0260	0.0072	3.92	40.95
	0.0263				
16	0.0415	0.0415	0.0116	6.26	65.38
	0.0415				
	0.0417	0.0419	0.0117	6.32	66.06
	0.0421				
24	0.0512	0.0512	0.0143	7.73	80.77
	0.0512				
	0.0513	0.0513	0.0143	7.73	80.77
	0.0513				

TABLE VII.
Uridinphosphoric Acid.

Time.	Mg ₂ P ₂ O ₇	Average	P in Mg ₂ P ₂ O ₇	P in free acid.	P in total P.
<i>hrs.</i>	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>	<i>per cent</i>	<i>per cent</i>
1	0.0034	0.0034	0.0009	0.57	5.91
	0.0034				
	0.0036	0.0036	0.0010	0.59	6.16
	0.0036				
2	0.0070	0.0070	0.0020	1.16	12.07
				
	0.0076	0.0075	0.0021	1.23	12.81
	0.0074				
4	0.0136	0.0136	0.0038	2.24	23.40
				
	0.0138	0.0138	0.0038	2.26	23.64
	0.0137				
8	0.0236	0.0236	0.0066	3.87	40.39
				
	0.0236	0.0237	0.0066	3.89	40.64
	0.0238				
16	.....	0.0407	0.0113	6.70	69.95
	0.0407				
	0.0413	0.0412	0.0115	6.77	70.69
	0.0410				

TABLE VIII.
Inosinphosphoric Acid.

Time.	Mg ₂ P ₂ O ₇	Average.	P in Mg ₂ P ₂ O ₇	P in free acid.	P in total P.
<i>hrs.</i>	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>	<i>per cent</i>	<i>per cent</i>
1	0.0033	0.0033	0.0009	0.52	5.79
	0.0033				
	0.0035	0.0035	0.0010	0.55	6.05
	0.0035				
2	0.0059	0.0060	0.0017	0.94	10.53
	0.0060				
	0.0062	0.0062	0.0017	0.97	10.88
	0.0062				
4	0.0135	0.0134	0.0037	2.08	23.42
	0.0132				
	0.0139	0.0138	0.0038	2.16	24.18
	0.0137				
8	0.0219	0.0220	0.0061	3.44	38.54
	0.0220				
	0.0215	0.0213	0.0059	3.32	37.28
	0.0210				
16	0.0362	0.0362	0.0101	5.66	63.48
	0.0362				
	0.0365	0.0364	0.0101	5.70	63.98
	0.0363				
24	0.0463	0.0460	0.0128	7.21	80.86
	0.0457				
	0.0457	0.0458	0.0128	7.16	80.35
	0.0459				

TABLE IX.
Hexothymidindiphosphoric Acid.

Time.	Mg ₃ P ₂ O ₇	Average.	P in Mg ₃ P ₂ O ₇	P in free acid.	P in total P.
<i>hrs.</i>	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>	<i>per cent</i>	<i>per cent</i>
1	0.0054	0.0053	0.0015	1.37	9.37
	0.0052				
	0.0051	0.0053	0.0015	1.37	9.37
	0.0055				
2	.....	0.0104	0.0029	2.67	18.23
	0.0104				
	0.0103	0.0104	0.0029	2.67	18.23
	0.0104				
4	0.0189	0.0185	0.0052	4.78	32.66
	0.0181				
	0.0183	0.0185	0.0052	4.78	32.66
	0.0186				
8	0.0314	0.0313	0.0087	8.07	55.19
	0.0312				
	0.0313	0.0315	0.0088	8.11	55.44
	0.0316				
16	0.0454	0.0452	0.0126	11.67	79.75
	0.0450				
	0.0456	0.0456	0.0127	11.78	80.51
	0.0456				
24	0.0523	0.0524	0.0146	13.52	92.40
	0.0524				
	0.0520	0.0522	0.0145	13.48	92.15
	0.0524				

Velocity Constants.

TABLE Ia.
Nucleic Acid.

t	$\text{Mg}_2\text{P}_2\text{O}_7 (x)$	$a - x$	$\frac{1}{t} \log \frac{a}{a - x}$
min.	gm.		
0			
60	0.0089	0.0481	0.0012
240	0.0308	0.0262	0.0014
	$a = 0.0570$		
Average.....			0.0013

TABLE IIa.
Nucleic Acid.

t	$\text{Mg}_2\text{P}_2\text{O}_7 (x)$	$a - x$	$\frac{1}{t} \log \frac{a}{a - x}$
min.	gm.		
0			
60	0.0062	0.0367	0.0011
120	0.0140	0.0289	0.0014
240	0.0252	0.0177	0.0016
480	0.0365	0.0064	0.0017
960	0.0438		
1,440	0.0462		
	$a = 0.0429$		
Average.....			0.0014

TABLE IIIa.
Nucleic Acid.

t	$\text{Mg}_2\text{P}_2\text{O}_7 (x)$	$a - x$	$\frac{1}{t} \log \frac{a}{a - x}$
min.	gm.		
0			
60	0.0059	0.0370	0.0011
120	0.0131	0.0298	0.0013
240	0.0254	0.0175	0.0016
480	0.0367	0.0062	0.0017
960	0.0437		
	$a = 0.0429$		
Average.....			0.0013

TABLE IVa.
Guanosinphosphoric Acid.

<i>t</i>	Mg ₂ P ₂ O ₇ (<i>x</i>)	<i>a - x</i>	$\frac{1}{t} \log \frac{a}{a-x}$
<i>min.</i>	<i>gm.</i>		
0			
60	0.0097	0.0433	0.00146
120	0.0199	0.0331	0.00170
240	0.0339	0.0191	0.00185
480	0.0449	0.0081	0.00170
720	0.0488	0.0042	0.00140
960	0.0495	0.0035	0.00188
	<i>a</i> = 0.0530		
Average.....			0 00167

TABLE Va.
Adenosinphosphoric Acid.

<i>t</i>	Mg ₂ P ₂ O ₇ (<i>x</i>)	<i>a - x</i>	$\frac{1}{t} \log \frac{a}{a-x}$
<i>min.</i>	<i>gm.</i>		
0			
60	0.0110	0.04674	0.00153
120	0.0224	0.03534	0.00178
240	0.0373	0.02044	0.00188
480	0.0478	0.00994	0 00159
960	0.0537	0.00404	0 00162
1,440	0.0543	0.00344	0 00156
	<i>a</i> = 0.05774		
Average... ..			0 00166

TABLE VIa.
Uridinphosphoric Acid.

<i>t</i>	Mg ₂ P ₂ O ₇ (<i>x</i>)	<i>a - x</i>	$\frac{1}{t} \log \frac{a}{a-x}$
<i>min.</i>	<i>gm.</i>		
0			
60	0.0030	0.0605	0.00035
120	0.0074	0.0561	0.00044
240	0.0136	0.0499	0.00044
480	0.0258	0.0377	0.00047
960	0.0417	0.0218	0.00048
1,440	0.0513	0 0122	0.00049
	<i>a</i> = 0.0635		
Average.....			0 00044

TABLE VIIa.
Uridinphosphoric Acid.

t	$\text{Mg}_2\text{P}_2\text{O}_7$	$a-x$	$\frac{1}{t} \log \frac{a}{a-x}$
<i>min.</i>	<i>gm.</i>		
0			
60	0.0035	0.0549	0.00045
120	0.0073	0.0511	0.00048
240	0.0137	0.0447	0.00048
480	0.0237	0.0347	0.00047
960	0.0410	0.0174	0.00054
	$a = 0.0584$		
Average.....			0.00048

TABLE VIIIa.
Inosinphosphoric Acid.

t	$\text{Mg}_2\text{P}_2\text{O}_7 (x)$	$a-x$	$\frac{1}{t} \log \frac{a}{a-x}$
<i>min.</i>	<i>gm.</i>		
0			
60	0.0034	0.0536	0.00044
120	0.0061	0.0509	0.00041
240	0.0136	0.0434	0.00049
480	0.0217	0.0353	0.00043
960	0.0363	0.0207	0.00046
1,440	0.0459	0.0111	0.00049
	$a = 0.0570$		
Average.....			0.00047

TABLE IXa.
Hexothymidindiphosphoric Acid.

t	$\text{Mg}_2\text{P}_2\text{O}_7 (x)$	$a-x$	$\frac{1}{t} \log \frac{a}{a-x}$
<i>min.</i>	<i>gm.</i>		
0			
60	0.0053	0.05142	0.000710
120	0.0104	0.04632	0.000733
240	0.0185	0.03822	0.000714
480	0.0314	0.02532	0.000730
960	0.0454	0.01132	0.000717
1,440	0.0522	0.00442	0.000752
	$a = 0.5672$		
Average.....			0.000726

THE ESTIMATION OF AMINOETHANOL AND OF CHOLINE APPEARING ON HYDROLYSIS OF PHOSPHATIDES.

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The method herein described is a modification of the one introduced by Thierfelder and Schulze.¹

In the original method, the separation of the two bases is based on the difference in the behavior of their hydrochlorides towards calcium oxide. Whereas the hydrochloride of aminoethanol is transformed by calcium oxide into the free base, the salt of choline remains unchanged.

In this particular the present method follows the directions of Thierfelder and Schulze. The difference is in the following.

The extraction of the free aminoethanol is accomplished in the original method by means of ether in a Soxhlet apparatus. This process is time-consuming and presents all the inconveniences of a Soxhlet extraction. We substituted in its stead extraction by means of boiling acetone, which is accomplished very rapidly.

A modification was also introduced for the isolation of choline. In the original process the hydrochloride of the base is extracted with alcohol. From this solution the base is precipitated with mercuric chloride, and this is then transformed into the hydrochloride and as such weighed and identified. However, the hydrochloride does not possess sufficiently desirable properties to encourage its use for the purpose of identification or of quantitative estimation. Hence the method was modified as follows:

The residue from acetone extraction is freed from hydrochloric acid and from lime and the choline is converted into the picrate. This if desired can be converted into the chloroplatinate.

¹Thierfelder, H., and Schulze, O., *Z. physiol. Chem.*, 1916, xcvi, 296.

EXPERIMENTAL.

The ether-soluble, acetone-insoluble lipoids from egg were freed from white matter, and hydrolyzed by boiling with 3 per cent sulfuric acid for 8 hours as recommended by MacLean.² After removal of the fatty acids by filtration, and the sulfuric acid by precipitation with barium hydroxide, the slightly acid filtrate was concentrated in vacuum, and precipitated with basic lead acetate as long as precipitate formed. The precipitate was filtered off, and the filtrate freed from lead with hydrogen sulfide. After addition of hydrochloric acid, the solution of the bases was repeatedly evaporated with water to remove the acetic acid. The residue was then extracted with absolute alcohol, filtered from inorganic salts, and evaporated. The latter operation was repeated twice. Finally the bases were taken up in water and made up to 25 cc. The solution contained 0.887 gm. of total nitrogen and 0.1836 gm. of amino nitrogen.

Of the above solution, 15 cc. were evaporated on the water bath to a small volume. The syrup was thoroughly mixed with an excess of calcium oxide, and extracted three times with dry acetone by boiling it for a few minutes with 75 cc. of that solvent. The combined filtered acetone extracts were acidified with hydrochloric acid, and evaporated in vacuum. The residue was taken up in water and evaporated to a syrup. The treatment with calcium hydroxide and extraction with smaller (25 cc.) portions of acetone were repeated. The final acetone extracts were allowed to stand in an ice chest and filtered. After acidification with hydrochloric acid, the acetone was removed by evaporation in vacuum, and the residue was made up to 10 cc. with water. The solution contained 0.0865 gm. of total nitrogen and 0.08535 gm. of amino nitrogen. Thus 77.5 per cent of the amino nitrogen had been extracted.

Of the above solution 9 cc. were strongly acidified with hydrochloric acid after which 1.9 gm. of gold chloride were added. On standing in a desiccator over sulfuric acid, large crystals separated. These were filtered off, pressed between filter paper, and allowed to dry. The yield was 1.5675 gm. or 71.3 per cent of the theoretical. The substance melted at 188–190°C., and analyzed as follows:

²MacLean, H., *Biochem. J.*, 1915, ix, 364.

0.1647 gm. of substance gave 0.0802 gm. of gold on ignition to constant weight.

	Calculated for $C_8H_{11}ON.HAuCl_4$ per cent	Found. per cent
Au.....	49.17	49.06

When the above compound was recrystallized from dilute hydrochloric acid, it separated as large glistening crystals with smooth surface, softening at 185° and melting at 190–192° (uncorrected). The recrystallized compound analyzed as follows:

0.1010 gm. of substance gave 0.0493 gm. of gold on ignition to constant weight.

	Calculated for $C_8H_{11}ON.HAuCl_4$ per cent	Found. per cent
Au.....	49.17	49.11

The residue from the acetone extract was treated with water and filtered from calcium hydroxide. The hydrochloric acid and the remaining calcium were removed from the solution with silver oxide and carbon dioxide, respectively. The filtrate, freed from hydrochloric acid and silver, was acidified with an alcoholic solution of picric acid, concentrated in vacuum, and allowed to stand in an ice chest. The precipitate was filtered off, and recrystallized from water. Beautiful long needles of choline picrate, softening at 238° and melting at 241–242°C. (uncorrected) were thus obtained. The substance analyzed as follows:

0.1302 gm. was reduced with 2 gm. of zinc dust in the presence of 10 cc. of HCl and a little water. The whole was then digested with sulfuric acid as usual, and distilled after addition of enough NaOH to bring all the zinc into solution. The distillate required for titration 15.57 cc. of 0.1 N acid.

0.4164 gm. of the picrate was extracted with ether in the presence of hydrochloric acid. The ether solution was dried over anhydrous sodium sulfate, filtered, and evaporated. The residue was dissolved in dry ether, filtered, and again evaporated. The residue weighed 0.291 gm.

	Calculated for $C_8H_{11}ON.C_6H_2O_7.N_3$ per cent	Found. per cent
N.....	16.86	16.75
Picric acid.....	68.97	69.80

0.7714 gm. of the picrate was extracted with ether as above. The aqueous solution was evaporated and the residue was taken

up in absolute alcohol and precipitated with an alcoholic solution of PtCl_4 . The yield of dried precipitate was 0.7065 gm. or 98.7 per cent of the theory. The chloroplatinate decomposed at 243°C . and had the following composition.

0.1050 gm. of substance gave on ignition to constant weight 0.0334 gm. of platinum.

	Calculated for $(\text{C}_2\text{H}_5\text{ONCl})_2\text{PtCl}_4$. <i>per cent</i>	Found. <i>per cent</i>
Pt.	31.64	31.80

UNSATURATED LIPOIDS OF THE LIVER.

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The subject of the lipoids of the liver calls for reinvestigation for several reasons. Previous investigators have laid claim to the discovery in this organ of substances which were not found among the lipoids of other organs. Furthermore, none of the phosphatides isolated from this organ has been identified with sufficient rigor.

The substances described as peculiar to liver tissue are jecorin,¹ and heparphosphatide.² Other unsaturated lipoids isolated from the liver are lecithin (Baskoff) and cephalin.³ The relation of the latter two lipoids to lecithin and to cephalin of other organs had not been established.

Regarding the unsaturated lipoids of other organs it is known that on the basis of their solubility they may be classified into three groups.

1. The acetone-soluble lipoids.
2. The acetone-insoluble, but alcohol-soluble.
3. The acetone-insoluble and alcohol-insoluble.

These differences in solubility are referred not to the pure substances but to material obtained by the extraction of the tissues with ether.

In this laboratory,⁴ it was found that the first fraction consisted principally of lecithin with small proportions of cephalin which can be readily removed; the second fraction consisted of lecithin containing larger proportions of cephalin; the third con-

¹ Drechsel, E., *J. prakt. Chem.*, 1886, xxxiii, 425.

² Baskoff, A., *Z. physiol. Chem.*, 1908, lvii, 395.

³ Frank, A., *Biochem. Z.*, 1913, 1, 277. Levene, P. A., and West, C. J., *J. Biol. Chem.*, 1916, xxiv, 115.

⁴ Levene, P. A., and Komatsu, S., *J. Biol. Chem.*, 1919, xxxix, 91.

sisted of very small proportions of lecithin and larger proportions of cephalin, but the bulk of the material of this fraction is composed of fragments of the other lipoids.

The present investigation aimed to find whether or not the enumerated three fractions with their general characteristics can be obtained from the liver tissue. The answer obtained was in the affirmative.

The acetone-soluble fraction led to the preparation of perfectly pure lecithin. The acetone-insoluble but alcohol-soluble fraction led to a lecithin and cephalin mixture in which cephalin constituted about 20 per cent of the material. From this fraction also practically pure lecithin could be prepared.

The acetone-insoluble and alcohol-insoluble fraction was found to be a mixture of little lecithin, little cephalin, and of a variety of fragments of these and perhaps of other lipoids.

In this respect, then, the lipid material obtained from the liver does not differ from that of other organs.

The study of the details of the structure of liver lecithin on one hand, and of the cephalin fraction on the other, however, has brought forward some new facts, which are important not only in reference to the special topic of liver lipoids but to that of the unsaturated lipoids in general.

Liver Lecithin.—The point of interest in connection with this substance lies in the nature of the fatty acids entering into the structure of its molecule. In the literature on this subject there exists utter confusion. A critical review of the subject will be given in a future publication. Here it suffices to note that liver lecithin contains in its molecule two fatty acids: one saturated stearic acid and the other unsaturated of the linolic series. There was no evidence of the presence of oleic acid. This conclusion was reached on the basis of the solubility of the barium salt of the unsaturated acid in ether, and on the basis of the hydrogen and iodine values of the fatty acid and of lecithin.

The hydrogen number (grams of hydrogen absorbed by 100 grams of substance) of a lecithin containing in its molecule linolic acid is 0.5018.

The number found for our lecithin was 0.5018.

The iodine number for two double bonds is 63.26.

The value we found was 72.73.

For linolic acid the hydrogen number is 1.439.

Our estimations on the unsaturated fatty acids from lecithin gave an average of 1.508.

The calculated iodine value is 180 and we found 210.

Whether or not the acid is linolic or its higher homologue is not absolutely certain. The analytical data obtained on the hydrogenated acid prepared in the course of the present work correspond to that required by theory for the higher homologue with C_{20} . Before a definite conclusion is reached a larger quantity of material is required, which will permit a more rigorous purification.

In this respect the lecithins obtained from the acetone-insoluble and from the acetone-soluble fractions are identical. The lecithin referred to in this work contained no free amino nitrogen.

Cephalin Fraction.—The point of interest in connection with this fraction is the following. As mentioned before, this fraction represents a mixture of different substances among which lecithin and cephalin are present. The special interest of the present work centers on the cephalin. A sample of cephalin having the elementary composition required by theory for this substance has not been obtained. Levene and West had obtained a sample of hydrogenated cephalin with an elementary composition required by theory. This finding established the correctness of the accepted theory of the structure of cephalin. For biological purposes, however, it still remains of importance to prepare a non-hydrogenated cephalin with a theoretical elementary composition. As yet this object has not been attained, but considerable progress towards this end is reported in this communication. Substances with elementary composition approaching closely the one required by theory and containing between 45 to 70 per cent of cephalin and the remaining part lecithin have been prepared.

On hydrogenation of this material a sample was obtained containing 80 per cent of hydrocephalin. The reduced material on hydrolysis yielded stearic acid and aminoethanol.

In a general way the preparation of this material is as follows: Crude cephalin is dissolved in glacial acetic acid. To this solution 99.5 per cent alcohol is added as long as a precipitate is formed. The filtrate is concentrated under diminished pressure

and the residue is emulsified in water and precipitated by means of acetone. The precipitate is the substance mentioned.

The details of the method are given in the experimental part.

A detailed study of the remaining portion of the cephalin fraction will be presented in a separate publication. The application of this new method of fractionation of the cephalin fraction to material obtained from other organs is in progress in this laboratory.

EXPERIMENTAL.

I. Acetone-Soluble Fraction.

Experiment 1.—400 lbs. of liver were minced, dried, and extracted five times with acetone, followed by an equal number of times with moist ether. The ether extracts were concentrated and precipitated with acetone. The precipitate was dissolved in ether and reprecipitated with acetone, the latter operation being repeated several times. All the acetone-ether solutions thus obtained were united with the original acetone extract, concentrated, allowed to stand at 10°C., and filtered. The filtrate was further concentrated *in vacuo* and poured into a large volume of acetone. On standing at 10°C., a syrupy precipitate formed which was separated by decantation. The acetone solution was again concentrated *in vacuo*. The residue was diluted with a little alcohol and precipitated with an alcoholic solution of cadmium chloride as long as a precipitate formed. After standing over night, the precipitate was filtered, redissolved in ether and water as usual, and reprecipitated with alcohol. The precipitate thus obtained weighed 250 gm. and contained 4.5 per cent of its total nitrogen in the form of amino nitrogen.

200 gm. of the above product were heated with 1.5 liters of toluene, allowed to cool, and centrifuged. A solution, No. 180, and a precipitate, No. 181, were thus obtained. The toluene solution was stirred into 6 liters of ether to which 1 per cent of water had been added. The precipitate, No. 180, was separated and washed with alcohol. The yield was 56 gm. of a substance giving the following analysis.

0.1026 gm. of substance gave on combustion 0.1750 gm. of CO₂, 0.0692 gm. of H₂O, and 0.0240 gm. of ash.

0.1898 gm. of substance used for Kjeldahl nitrogen estimation required for neutralization 1.86 cc. of 0.1 N acid.

0.2848 gm. of substance gave on fusion 0.0314 gm. of $Mg_2P_2O_7$.

0.4746 " " " " " " " 0.1340 " " $CdSO_4$.

2 gm. of substance were hydrolyzed for a determination of the nitrogen distribution with 10 per cent HCl, neutralized, and then concentrated to 10 cc.

5 cc. of this solution for Kjeldahl determination required 3.95 cc. of 0.1 N acid for neutralization.

2 cc. of this solution gave no nitrogen gas by a Van Slyke determination.

	Calculated for $C_{44}H_{80}O_{10}NP \cdot 2CdCl_2$ per cent	Found. per cent
C.....	45.13	46.51
H.....	7.35	7.55
N.....	1.19	1.36
P.....	2.65	3.06
Cd.....	19.20	15.17
$NH_2 N$	0	0
Total N	100	100

The precipitate, No. 181, mentioned above, dissolved for the most part in 500 cc. of benzene. The filtered solution was poured into 95 per cent alcohol and a precipitate, No. 181, was obtained. The yield was 40 gm. of a substance containing 0.5 per cent of its total nitrogen in the form of amino nitrogen.

1.5 gm. of substance were hydrolyzed for a determination of the nitrogen distribution with 10 per cent HCl, neutralized, and then concentrated to 10 cc.

5 cc. of this solution required 3.40 cc. of 0.1 N acid for neutralization in Kjeldahl determination.

2 cc. of this solution in a Van Slyke determination gave 0.02 cc. of N gas, $P = 760$ mm., $T = 23^\circ C$.

Experiment 2.—In a second experiment the precipitation of the concentrated acetone liquors with acetone was omitted. In this case, however, it was more difficult to obtain a fraction free from amino nitrogen. After repeated solution in benzene and precipitation with moist ether, two fractions were obtained. Of these, one consisting of 50 gm., was amino nitrogen-free, and the other, 95 gm., contained 0.5 per cent of its total nitrogen in the form of amino nitrogen.

20 gm. of the lecithin-cadmium chloride compound was freed from cadmium chloride by the method described by Levene and West. The lecithin thus obtained was purified once by Mac-

Lean's water-acetone method. Attempts to reduce the product failed. Hence the purification with water and acetone was repeated four times, after which the precipitate was dissolved in ether and reprecipitated with dry acetone.

The following analytical figures on the unreduced material were obtained.

0.1074 gm. of substance gave on combustion 0.2556 gm. of CO_2 , 0.1014 gm. of H_2O , and 0.0102 gm. of ash.

0.1940 gm. of substance used for Kjeldahl nitrogen estimation required for neutralization 2.71 cc. of 0.1 N acid.

0.2910 gm. of substance gave on fusion 0.0373 gm. of $\text{Mg}_2\text{P}_2\text{O}_7$.

	Calculated for $\text{C}_{44}\text{H}_{70}\text{O}_8\text{NP}$ per cent	Found. per cent
C.....	65.75	65.72
H.....	10.70	10.70
N.....	1.74	1.97
P.....	3.86	3.61

0.9733 gm. of substance dissolved in 95 per cent alcohol containing one drop of acetic acid was reduced with hydrogen in the presence of palladium by the method of Paal. The palladium and most of the alcohol was saturated with hydrogen before the introduction of the substance. 59.7 cc. of hydrogen gas at 767 mm. pressure and 21°C . were absorbed (54 cc. were absorbed in 1 hour and 15 minutes, and after 4 hours the figures given above were obtained). Reduced to standard conditions, 59.7 cc. at above temperature and pressure are equivalent to 54.4 cc. or 0.00489 gm. of hydrogen gas.

0.3106 gm. of substance absorbed 0.2259 gm. of iodine when titrated according to the methods of Wijs.

	Calculated for $\text{C}_{44}\text{H}_{70}\text{O}_8\text{NP}$	Found.
Hydrogen number.....	0.5018	0.5018
Iodine "	63.26	72.73

Fatty Acids of Lecithin.

52 gm. of No. 180 and 38 gm. of No. 181 were combined, powdered, and boiled 8 hours with 700 cc. of 10 per cent hydrochloric acid. After cooling, the cake of fatty acids was filtered off. The acids were repeatedly melted in hot water, allowed to cool, and separated from the water, until the wash water was neutral to litmus. The washed acids weighed about 42 gm. They were converted into barium salts by the method described

by Levene and Meyer,⁵ using, however, an aqueous solution of barium hydroxide instead of a methyl alcoholic solution as described in the original method. The barium salts were extracted with ether until practically nothing further was taken up by the solvent. A residue, No. 185, and a solution, No. 186, of barium salts were thus obtained. The barium salts of the saturated acids, No. 185, were decomposed with 10 per cent hydrochloric acid on the water bath, and washed free from inorganic acids. The fatty acids weighing nearly 21 gm., were converted into lead salts by adding an aqueous solution of lead acetate to a methyl alcoholic solution of the acids, followed by a few drops of ammonia water. The lead salts were filtered and washed with water and acetone. The salts were then dissolved in hot benzene and decomposed with hydrogen sulfide. After removing the lead sulfide, the benzene solution was allowed to stand in an ice chest and a precipitate, No. 185, was obtained. The fatty acids in this fraction melted at 68–68.5°C. (corrected) heated at 5 to 6 seconds per degree. After one recrystallization from benzene, the acid melted at 69–70° (corrected). All melting points recorded in this report were taken at such a rate that 5 to 7 seconds were consumed for each degree rise.

The analysis on No. 185 was as follows:

0.1000 gm. of substance gave on combustion 0.2802 gm. of CO₂ and 0.1170 gm. of H₂O.

1.1546 gm. of substance in a molecular weight determination, dissolved in 10 cc. of toluene and 25 cc. of methyl alcohol, required for neutralization 8.08 cc. of 0.5 N alkali.

	Calculated for C ₁₈ H ₃₆ O ₂ per cent	Found. per cent
C.....	75.98	76.41
H.....	12.76	13.09
Molecular weight.....	284	285

The combined benzene filtrates from the above acid were concentrated, and a small volume of acetone was added. After standing in an ice chest, the fatty acids were filtered off and dried. The acids in this fraction melted at 60°C. (corrected) and had the following composition.

⁵ Levene, P. A., and Meyer, G. M., *J. Biol. Chem.*, 1917, xxxi, 627.

0.1005 gm. of substance gave on combustion 0.2809 gm. of CO_2 and 0.1165 gm. of H_2O .

1.2156 gm. of substance in a molecular weight determination titrated as above required for neutralization 8.82 cc. of 0.5 N NaOH.

	Calculated for $\text{C}_{18}\text{H}_{32}\text{O}_2$ per cent	Found. per cent
C.....	75.98	76.22
H.....	12.76	12.97
Molecular weight.....	284	275

These acids were again converted into lead salts, which were suspended in ether to remove any trace of unsaturated acids. The free acid after liberation was recrystallized from 95 per cent alcohol, and it then melted at 66–67°C. (corrected) and analyzed as follows:

0.1000 gm. of substance gave on combustion 0.2784 gm. of CO_2 , 0.1164 gm. of H_2O , and no ash.

0.5831 gm. of substance for a molecular weight determination titrated as above required for neutralization 4.20 cc. of 0.5 N NaOH.

	Calculated for $\text{C}_{18}\text{H}_{32}\text{O}_2$ per cent	Found. per cent
C.....	75.98	75.95
H.....	12.76	13.02
Molecular weight.....	284	278

This substance was apparently stearic acid containing a small amount of impurities.

The ether solution of the barium salts of the unsaturated acids, No. 186, was decomposed with 10 per cent hydrochloric acid in the presence of benzene and washed free of mineral acid as before. The benzene solution of the fatty acids was filtered, evaporated, and finally the acids were dried in a 90° air bath. 20 gm. of a liquid were thus obtained which remained fluid in the ice chest.

4.9110 gm. of substance, dissolved in 95 per cent alcohol and hydrogenated as previously described, absorbed 1.024 liters of hydrogen at 755.5 mm. pressure and 22°C., or 0.0825 gm. of hydrogen.

0.2386 gm. of substance absorbed 0.5028 gm. of iodine when titrated according to the method of Wijs.

	Calculated for $\text{C}_{18}\text{H}_{32}\text{O}_2$	Found.
Hydrogen number.....	1.439	1.679
Iodine "	180	210

100 gm. of the same sample of lecithin cadmium chloride compound from which the free lecithin had been obtained were hydrolyzed as previously described. A sample of the free acids was dissolved in ether and repeatedly washed with water. The ether solution was evaporated and the acids were dried in a steam-heated oven.

0.7961 gm. of the mixed acids was dissolved in 95 per cent alcohol and reduced as previously described. The reduction was nearly completed in 15 minutes. The acids absorbed 75.8 cc. of hydrogen at 762 mm. pressure and 22.6°C., or 0.00611 gm. of hydrogen.

	Calculated for $C_{18}H_{34}O_2$	Found.
Hydrogen number.....	0.714	0.768

It was found that the lead salt of oleic acid was readily soluble in ether while the barium salt of this acid was almost insoluble in that solvent. Hence the rest of the fatty acids were converted into lead salts and extracted with ether. The unsaturated acids were liberated in the ether solution with hydrochloric acid and washed free of mineral acid, after which the ether solution was evaporated. The fatty acids were converted into barium salts and extracted with ether. Only a small residue remained after this extraction, and this gave only a trace of fatty acids after decomposition with hydrochloric acid.

The extracted barium salts were decomposed with hydrochloric acid in the presence of ether and washed free of mineral acid. The ether solution was evaporated and dried as previously described. A liquid was thus obtained which on hydrogenation gave the following figures.

0.8114 gm. of substance, dissolved in 95 per cent alcohol and reduced by Paal's method, absorbed 185.2 cc. of hydrogen at 760 mm. pressure and 23°C., or 0.00997 gm. of hydrogen.

	Calculated for $C_{18}H_{34}O_2$	Found.
Hydrogen number.....	1.439	1.339

The unsaturated acids were hydrogenated by Paal's method, and the reduced acids purified by converting them into lead salts. Repeated recrystallization from 95 per cent alcohol gave acids which melted at 69–70°C. (corrected). With Kahlbaum's stearic, which had a melting point of 68–69°, it melted at 63°C. The substance had the following composition.

0.1006 gm. of substance gave on combustion 0.2850 gm. of CO_2 and 0.1194 gm. of H_2O .

0.1004 gm. of substance gave on combustion 0.2838 gm. of CO_2 and 0.1184 gm. of H_2O .

1.0718 gm. of substance for a molecular weight determination dissolved in toluene and methyl alcohol required for neutralization 6.72 cc. of 0.5 N NaOH.

	Calculated for $\text{C}_{20}\text{H}_{40}\text{O}_2$ per cent	Found. per cent
C.....	76.92	77.25, 77.08
H.....	12.82	13.28, 13.19
Molecular weight.....	312	319

Further investigation will be required before a final decision as to the actual composition can be reached.

II. Acetone-Insoluble, Alcohol-Soluble Fraction.

Experiment 3.—A lecithin-cadmium chloride compound almost free from amino nitrogen was obtained from the acetone-insoluble, alcohol-soluble fraction of the lipoids. The solution of the lipoids in alcohol was precipitated with cadmium chloride as previously described, and the precipitate was dissolved in benzene and precipitated with ether saturated with water. The operation was repeated four times. At first a large volume of ether was employed, and it was found necessary to add alcohol to accomplish a satisfactory separation. A yield of 57 gm. of a snow-white substance was thus obtained, which contained 0.42 per cent of its total nitrogen in the form of amino nitrogen.

2 gm. of the substance were hydrolyzed to determine the nitrogen distribution, neutralized, and concentrated to 10 cc.

5 cc. of the solution required for neutralization 4.63 cc. of 0.1 N acid in Kjeldahl determination.

2 cc. of this solution gave 0.02 cc. of N gas in a Van Slyke determination, $P = 755$ mm., $T = 23^\circ\text{C}$.

The fatty acids from this fraction were obtained as previously described. The mixed acids had the following characteristics.

1.0025 gm. of substance reduced by Paal's method absorbed 97 cc. of H at 761 mm. pressure and 22.2°C ., or 0.00751 gm. of hydrogen.

0.3113 gm. of substance absorbed 0.3217 gm. of iodine when titrated according to the method of Wijs.

	Calculated for $C_{15}H_{24}O_2$	Found.
Hydrogen number.....	0.714	0.750
Iodine "	90	103

The saturated acids after one recrystallization from 95 per cent alcohol melted at 6.85° C. (corrected) and had the following composition.

0.1008 gm. of substance gave on combustion 0.2804 gm. of CO_2 and 0.1160 gm. of H_2O .

0.9066 gm. of substance in a molecular weight determination dissolved in toluene and methyl alcohol required for neutralization 6.40 cc. of 0.5 N NaOH.

	Calculated for $C_{15}H_{24}O_2$ per cent	Found. per cent
C.....	75.98	75.87
H.....	12.76	12.88
Molecular weight.....	284	283

Recrystallized from alcohol, this acid melted at 70-72°C. (corrected). A mixture with Kahlbaum's stearic acid, having a melting point of 68-69°, melted at 68.5°C. (corrected).

The ether solution of the barium salts of the unsaturated acids was evaporated. Attempts to dissolve the residue in pure benzene failed as a gelatinous transparent suspension was formed from which the salts could again be separated by centrifuging. The salts dissolved readily in benzene containing 5 per cent absolute alcohol, from which they were precipitated by pouring the solution into a large volume of absolute alcohol. The substance was dried in vacuum over sulfuric acid, at temperature of boiling water, and had the following barium content.

0.0973 gm. of substance gave on fusion 0.0322 gm. of $BaSO_4$.

	Calculated for $C_{15}H_{22}O_4Ba$ per cent	Found. per cent
Ba.....	19.76	19.48

After allowing the barium salts of the above acids to stand in a desiccator over sulfuric acid for more than a week, their solubility in ether had decreased, and the free acids obtained by decomposition with hydrochloric acid formed a viscous syrup. Oxidation

had evidently taken place for on hydrogenation the following figures were obtained.

0.6275 gm. of substance reduced by Paal's method absorbed 71.3 cc. of H at 760 mm. pressure and 22.8°C. or 0.00571 gm. of hydrogen.

0.3455 gm. of substance absorbed 0.4161 gm. of iodine when titrated according to the method of Wijs.

	Calculated for $C_{18}H_{30}O_2$	Found.
Hydrogen number.....	1.439	0.911
Iodine "	180	120

Experiment 4.—Another sample of acetone-insoluble, alcohol-soluble lipid was purified by water and acetone, dried, dissolved in glacial acetic acid, and poured into a large volume of dry acetone. The mixture was allowed to stand at 0°C. over night, when a small precipitate, No. 68, was obtained. This substance had the following composition.

0.1002 gm. of substance gave on combustion 0.2227 gm. of CO_2 , 0.0823 gm. of H_2O , and 0.0107 gm. of ash.

0.1960 gm. of substance used for Kjeldahl nitrogen estimation required for neutralization 3.14 cc. of 0.1 N acid.

0.2940 gm. of substance gave on fusion 0.0377 gm. of $Mg_2P_2O_7$.

1 gm. was hydrolyzed in estimating the nitrogen distribution, neutralized, concentrated, and made up to 10 cc.

5 cc. of this solution required 2.92 cc. of 0.1 N acid for neutralization in Kjeldahl determination.

2 cc. of this solution gave on Van Slyke determination 1.48 cc. of N gas; $P = 764$ mm., $T = 21^\circ C$.

Found: C = 61.23, H = 9.44, N = 2.30, P = 3.66 per cent.

$$\frac{NH_2 N}{\text{Total N}} = \frac{51.4}{100}$$

The acetic acid-alcohol filtrate from No. 68 was evaporated *in vacuo* to a thick syrup, keeping the temperature as low as possible. The residue was emulsified with water and precipitated with a small volume of acetone. The precipitate was dissolved in ether, reprecipitated by acetone, and dried. This substance had the following composition.

0.1059 gm. of substance gave on combustion 0.2523 gm. of CO_2 , 0.0971 gm. of H_2O , and 0.0101 gm. of ash.

0.2882 gm. of substance used for Kjeldahl nitrogen estimation required for neutralization 4.39 cc. of 0.1 N acid.

0.2885 gm. of substance gave on fusion 0.0405 gm. of $Mg_2P_2O_7$.

0.5 gm. was hydrolyzed for an estimation of the nitrogen distribution, neutralized, concentrated, and made up to 10 cc.

5 cc. of this solution required 2.16 cc. of 0.1 N acid for neutralization in Kjeldahl determination.

2 cc. of this solution in a Van Slyke determination gave 0.33 cc. of N gas; $P = 768$ mm., $T = 24^\circ C$.

Found: C = 65.38, H = 10.12, N = 2.17, P = 3.92 per cent.

$$\frac{NH_3 N}{\text{Total N}} = \frac{13.7}{100}$$

Experiment 5.—Another sample of crude lecithin, which had not been fractionated with acetic acid-acetone, was united with the substance of the above composition and reduced by the method of Paal. After the palladium was removed, the alcoholic solution was allowed to stand in an ice chest when the lipoids crystallized and were filtered off. 56 gm. of lipoids thus obtained were dissolved in chloroform and poured into several volumes of dry ether. The precipitate, weighing 48 gm., was dissolved in 750 cc. of a mixture of methyl ethyl ketone and chloroform as described by Levene and West.⁶ 31 gm. separated when the mixture was allowed to stand at room temperature over night. This substance had the following composition.

0.1046 gm. of substance gave on combustion 0.2544 gm. of CO_2 , 0.1040 gm. of H_2O , and 0.0104 gm. of ash.

0.2980 gm. of substance used for Kjeldahl nitrogen estimation required for neutralization 3.54 cc. of 0.1 N acid.

0.2944 gm. of substance gave on fusion 0.0396 gm. of $Mg_2P_2O_7$.

0.5 gm. was hydrolyzed for determination of the nitrogen distribution, neutralized, concentrated, and made up to 10 cc.

5 cc. of this solution required for neutralization 2.06 cc. of 0.1 N acid for a Kjeldahl estimation.

2 cc. of this solution gave in a Van Slyke determination 0.52 cc. of N gas; $P = 773$ mm., $T = 25^\circ C$.

Found: C = 67.27, H = 11.28, N = 1.70, P = 3.79 per cent.

$$\frac{NH_3 N}{\text{Total N}} = \frac{25.8}{100}$$

The filtrate from the above compound was allowed to stand in the ice chest, when a substance of the following composition separated.

⁶ Levene, P. A., and West, C. J., *J. Biol. Chem.*, 1918, xxxv, 285.

0.1035 gm. of substance gave on combustion 0.2499 gm. of CO_2 , 0.0964 gm. of H_2O , and 0.0094 gm. of ash.

0.1950 gm. of substance used for Kjeldahl nitrogen estimation required for neutralization 2.74 cc. of 0.1 N acid.

0.2925 gm. of substance gave on fusion 0.0407 gm. of $\text{Mg}_2\text{P}_2\text{O}_7$.

1 gm. was hydrolyzed for estimation of the nitrogen distribution, neutralized, concentrated, and made up to 10 cc.

5 cc. of this solution required for neutralization 4.72 cc. of 0.1 N acid for Kjeldahl determination.

2 cc. of this solution used for Van Slyke determination gave 0.90 cc. of N gas; $P = 765$ mm., $T = 22^\circ\text{C}$.

Found: C = 66.0, H = 10.46, N = 1.96, P = 3.87 per cent.

$$\frac{\text{NH}_3 \text{ N}}{\text{Total N}} = \frac{19.3}{100}$$

III. Cephalin Fraction.

The lipoids precipitated by pouring their solution in ether into a large volume of alcohol were extracted four times with 95 per cent alcohol at 60°C . for 40 minutes as described by Levene and Komatsu.⁴ The residue was dissolved in ether, precipitated with acetone, and dried. This substance, No. 6, had the following composition.

0.0968 gm. of substance on combustion gave 0.2180 gm. of CO_2 , 0.0750 gm. of H_2O , and 0.0122 gm. of ash.

0.1906 gm. of substance used for Kjeldahl nitrogen estimation required for neutralization 2.84 cc. of 0.1 N acid.

0.2858 gm. of substance gave on fusion 0.0400 gm. of $\text{Mg}_2\text{P}_2\text{O}_7$.

Found: C = 63.07, H = 8.96, N = 2.17, P = 4.15 per cent.

The substance was further fractionated by dissolving it in ether and pouring the solution into a large volume of alcohol. Finally the material was separated into two fractions by dissolving it in a small volume of ether and allowing it to stand at 0° for 24 hours. An ether solution, No. 26, and a precipitate, No. 28, were thus obtained. Both Nos. 26 and 28 were then separately dissolved in ether and precipitated with a small volume of alcohol, this operation being repeated several times. After this treatment No. 26 analyzed as follows:

0.1044 gm. of substance gave on combustion 0.2278 gm. of CO_2 , 0.0830 gm. of H_2O , and 0.0148 gm. of ash.

0.3155 gm. of substance used for Kjeldahl nitrogen estimation required for neutralization 3.04 cc. of 0.1 N acid.

0.2895 gm. of substance gave on fusion 0.0400 gm. of $Mg_2P_2O_7$.

1.4 gm. of substance was hydrolyzed to determine the nitrogen distribution, neutralized, concentrated, and made up to 10 cc.

5 cc. of this solution required for neutralization 8.05 cc. of 0.1 N acid in a Kjeldahl determination.

2 cc. of this solution used for a Van Slyke determination gave 1.69 cc. of N gas, $P = 757$ mm., $T = 23^\circ C$.

Found: C = 62.86, H = 9.39, N = 1.86, P = 4.06 per cent.

$$\frac{NH_3 N}{Total N} = \frac{55.2}{100}$$

No. 28 analyzed as follows:

0.2381 gm. of substance used for Kjeldahl nitrogen estimation required for neutralization 2.95 cc. of 0.1 N acid.

0.3000 gm. of substance gave on fusion 0.0514 gm. of $Mg_2P_2O_7$.

1 gm. was hydrolyzed to determine the nitrogen distribution, neutralized, concentrated, and made up to 10 cc.

5 cc. of this solution required for neutralization in a Kjeldahl determination 3.25 cc. of 0.1 N acid.

2 cc. of this solution used for a Van Slyke estimation gave 1.58 cc. of N gas, $P = 768.2$ mm., $T = 25^\circ C$.

Found: N = 1.73, P = 4.77 per cent.

$$\frac{NH_3 N}{Total N} = \frac{48.7}{100}$$

A substance analyzing unusually well was obtained from No. 28 by the following procedure. The material was dissolved in three parts of glacial acetic acid with slight warming. The solution was poured into ten parts of alcohol, the precipitate separating on standing in the cold. This was removed by filtration and the filtrate then concentrated *in vacuo*, without heat, to a thick syrup. Attempts to dissolve the residue in ether and reprecipitate it with acetone failed as the lipoid of this fraction was soluble in acetone in the presence of acetic acid. However, the syrup was emulsified with water and precipitated with a small quantity of acetone as described by MacLean for the purification of lecithin. The precipitate was dissolved in ether and reprecipitated with acetone. This substance had the following composition.

0.1036 gm. of substance gave on combustion 0.2372 gm. of CO_2 , 0.0838 gm. of H_2O , and 0.0137 gm. of ash.

0.3519 gm. of substance used for Kjeldahl nitrogen estimation required for neutralization 3.54 cc. of 0.1 N acid.

0.2916 gm. of substance gave on fusion 0.0357 gm. of $\text{Mg}_2\text{P}_2\text{O}_7$.

0.8 gm. was hydrolyzed to determine the nitrogen distribution, neutralized, concentrated, and made up to 10 cc.

5 cc. of this solution required for a Kjeldahl determination 1.56 cc. of 0.1 N acid.

2 cc. of this solution in a Van Slyke estimation gave 1.04 cc. of N gas, $P = 759$ mm., $T = 24^\circ\text{C}$.

Found: C = 66.00, H = 9.5, N = 1.487, P = 3.60 per cent.

$$\frac{\text{NH}_2 \text{ N}}{\text{Total N}} = \frac{66.4}{100}$$

It was later demonstrated that the acetone-insoluble material, precipitated from its solution in ether with alcohol at room temperature, was well adapted as a starting material for obtaining a substance of the above composition. The material was simply dissolved in acetic acid and poured into a large volume of dry alcohol. The filtrate was treated as previously described. On samples where the carbon was still low, the process was repeated, thereby increasing the carbon content, while the ratio of the amino nitrogen to total nitrogen remained the same. It was more difficult to obtain this material from crude cephalin which had been purified by the hydrochloric acid method. The analyses of some of these fractions are given in Table I.

Several samples of this material were combined, dissolved in hot absolute alcohol, and placed in an ice chest. The precipitate was separated by filtration. The filtrate was evaporated *in vacuo*, and the residue was dissolved in hot methyl ethyl ketone. On cooling to room temperature a small amount of a white solid separated. This substance, No. 131, had the following composition.

0.1000 gm. of substance gave on combustion 0.2400 gm. of CO_2 , 0.0966 gm. of H_2O , and 0.0100 gm. of ash.

0.1894 gm. used for Kjeldahl nitrogen estimation required 3.96 cc. of 0.1 N acid for neutralization.

0.2841 gm. of substance gave on fusion 0.0366 gm. of $\text{Mg}_2\text{P}_2\text{O}_7$.

1 gm. was hydrolyzed to estimate the nitrogen distribution, neutralized, concentrated, and made up to 10 cc.

5 cc. of this solution required for neutralization in a Kjeldahl determination 3.25 cc. of 0.1 N acid.

2 cc. of this solution gave in a Van Slyke determination 0.65 cc. of N gas, $P = 752$ mm., $T = 25^\circ\text{C}$.

Found: C = 66.78, H = 11.03, N = 2.93, P = 3.66 per cent.

$$\frac{\text{NH}_2 \text{ N}}{\text{Total N}} = \frac{19.7}{100}$$

The filtrate from No. 131 was evaporated *in vacuo*. The residue was taken up in 95 per cent alcohol, slightly acidified with acetic acid, and reduced by Paal's method. After hydrogenation had proceeded for a time a considerable quantity of solids separated which apparently hindered further catalytic action. The tubes were emptied, the solids were separated by filtration in an ice chest, and the hydrogenation was repeated on the filtrate. The

TABLE I.

No.	C	H	N	P	$\frac{\text{NH}_3\text{N}}{\text{Total N}}$
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	
82	64.42	9.92	1.91	3.80	$\frac{45.3}{100}$
95	65.76	9.83	1.52	3.37	$\frac{60.1}{100}$
97	66.00	10.43	1.79	3.58	$\frac{44.1}{100}$
104	64.93	10.03	2.28	3.64	
122	64.78	8.97			$\frac{55.9}{100}$
217	66.46	10.10	2.36	3.48	$\frac{52.2}{100}$
Calculated: for $\text{C}_{44}\text{H}_{86}\text{O}_9\text{NP}$ (lecithin)	65.60	10.79	1.74	3.86	$\frac{00}{100}$
for $\text{C}_{41}\text{H}_{80}\text{O}_9\text{NP}$	66.17	10.57	1.88	4.17	$\frac{100}{100}$

reduced lipoids thus obtained were dissolved in hot absolute alcohol, filtered from palladium, and allowed to cool to room temperature. The resultant precipitate, No. 132, gave the following analysis.

0.1023 gm. of substance gave on combustion 0.2416 gm. of CO_2 , 0.0910 gm. of H_2O , and 0.0113 gm. of ash.

0.1947 gm. used for Kjeldahl nitrogen estimation required for neutralization 2.58 cc. of 0.1 N acid.

0.2948 gm. of substance gave on fusion 0.0406 gm. of $Mg_2P_2O_7$.

1 gm. was hydrolyzed to estimate the nitrogen distribution, neutralized, concentrated, and made up to 10 cc.

5 cc. of this solution required for neutralization in a Kjeldahl determination 3.55 cc. of 0.1 N acid.

1.5 cc. of this solution gave in a Van Slyke determination 1.94 cc. of N gas, $P = 752$ mm., $T = 24^\circ C$.

Found: C = 65.98, H = 10.30, N = 1.89, P = 3.93 per cent.

$$\frac{NH_3 \text{ N}}{\text{Total N}} = \frac{71.8}{100}$$

The filtrate from No. 132 was allowed to stand in an ice chest whereupon a precipitate, No. 137, was obtained. This substance gave the following analysis.

0.1029 gm. of substance gave on combustion 0.2480 gm. of CO_2 , 0.0942 gm. of H_2O , and 0.0105 gm. of ash.

0.1944 gm. of substance used for Kjeldahl nitrogen estimation required for neutralization 2.03 cc. of 0.1 N acid.

0.2916 gm. of substance gave on fusion 0.0408 gm. of $Mg_2P_2O_7$.

1 gm. was hydrolyzed to determine the nitrogen distribution, neutralized, concentrated, and made up to 10 cc.

5 cc. of this solution required for neutralization in a Kjeldahl determination 3.45 cc. of 0.1 N acid.

2 cc. of this solution gave in a Van Slyke determination 1.79 cc. of N gas, $P = 750$ mm., $T = 25^\circ$.

Found: C = 66.68, H = 10.36, N = 2.02, P = 3.94 per cent.

$$\frac{NH_3 \text{ N}}{\text{Total N}} = \frac{51.1}{100}$$

The filtrate from No. 137 was evaporated. The residue was dissolved in ether and precipitated with acetone. The precipitate, No. 139, gave the following analysis.

0.0944 gm. of substance gave on combustion 0.2232 gm. of CO_2 , 0.0906 gm. of H_2O , and 0.0094 gm. of ash.

0.1798 gm. of substance used for Kjeldahl nitrogen estimation required for neutralization 2.18 cc. of 0.1 N acid.

0.2697 gm. of substance gave on fusion 0.0368 gm. of $Mg_2P_2O_7$.

0.5 gm. was hydrolyzed to determine the nitrogen distribution, neutralized, concentrated, and made up to 10 cc.

5 cc. of this solution required for neutralization in a Kjeldahl determination 1.61 cc. of 0.1 N acid.

1.75 cc. of this solution gave in a Van Slyke determination 0.62 cc. of N gas, $P = 773$ mm., $T = 24^\circ$.

Found: C = 65.28, H = 10.87, N = 1.72, P = 3.84 per cent.

$$\frac{\text{NH}_4\text{N}}{\text{Total N}} = \frac{44.6}{100}$$

After washing the reduction tubes with hot alcohol a solid remained attached to the walls, which was not easily removed with that solvent. This material was dissolved in a mixture of chloroform and alcohol and filtered. After evaporation of the solvent, the residue was dissolved in hot absolute alcohol, filtered, and allowed to cool to room temperature. The precipitate, No. 142, gave a clear colorless filtrate after hydrolysis with hydrochloric acid, and this solution did not reduce Fehling's solution. No. 142 had the following composition.

0.1040 gm. of substance on combustion gave 0.2472 gm. of CO₂, 0.0970 gm. of H₂O, and 0.0109 gm. of ash.

0.1954 gm. of substance used for Kjeldahl nitrogen estimation required for neutralization 2.28 cc. of 0.1 N acid.

0.2938 gm. of substance gave on fusion 0.0402 gm. of Mg₂P₂O₇.

0.5 gm. of substance was hydrolyzed to determine the nitrogen distribution, neutralized, concentrated, and made up to 10 cc.

5 cc. of this solution required for neutralization in a Kjeldahl determination 1.07 cc. of 0.1 N acid.

2 cc. of this solution gave in a Van Slyke determination 0.87 cc. of N gas, $P = 754$ mm., $T = 23^\circ$.

Found: C = 66.05, H = 10.62, N = 1.66, P = 3.87 per cent.

$$\frac{\text{NH}_4\text{N}}{\text{Total N}} = \frac{80.7}{100}$$

10 gm. of No. 139 were hydrolyzed and the bases and acids were obtained as previously⁷ described. In this case, however, the extraction with alcohol and acetone was not repeated. 0.035 gm. of amino nitrogen was obtained in the acetone extract, and from this 0.33 gm. of a gold salt was obtained which melted at 188°C. and analyzed as follows:

0.1159 gm. of substance gave 0.0570 gm. of Au on ignition to constant weight.

	Calculated for C ₂ H ₅ ON·AuCl ₄ per cent	Found. per cent
Au.....	49.17	49.18

⁷ Levene, P. A., and Ingvaldsen, T., *J. Biol. Chem.*, 1920, xliii, 355.

The residue from the acetone extract gave a picrate which melted at 240–241° and had the following nitrogen content.

0.2448 gm. of substance used for a modified Kjeldahl nitrogen estimation required for neutralization 29.3 cc. of 0.1 N acid.

	Calculated for $C_8H_{15}ON.C_6H_5O_7Na_3$ per cent	Found per cent
N.....	16.86	16.75

The fatty acids were obtained as previously described. The acids were once recrystallized from acetone, and then from ether. The substance melted at 68°–69°C. (corrected) and had the following composition.

0.1012 gm. of substance gave 0.2810 gm. of CO_2 , 0.1146 gm. of H_2O , and no ash.

1.0294 gm. dissolved in benzene and methyl alcohol in a molecular weight determination required for neutralization 35.3 cc. of a 0.1 N NaOH solution.

	Calculated for $C_{18}H_{33}O_2$ per cent	Found per cent
C.....	75.98	75 72
H.....	12.76	12 67
Molecular weight.....	284	291

STRUCTURE OF YEAST NUCLEIC ACID.

AMMONIA HYDROLYSIS: ON THE SO CALLED TRINUCLEOTIDE OF THANNHAUSER AND DORFMÜLLER.

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In a previous communication¹ were presented the theoretical arguments which militated against the conception of the structure of yeast nucleic acid formulated by Thannhauser and Dorfmueller.²

In order to add weight to the theoretical considerations, it seemed desirable to demonstrate by experiment that the trinucleotide described by these authors was in reality a mixture of mononucleotides.

These authors state: "Levene regards yeast nucleic acid as a tetranucleotide. If this view is correct then on mild hydrolysis one should obtain the four nucleotides." Instead, Thannhauser and Dorfmueller claimed to have isolated uridinphosphoric acid and a trinucleotide.

Hence, if it were shown by experiment that the four mononucleotides were formed under conditions of hydrolysis employed by these authors, then the theory advanced by them would automatically fall. True, the present writer has demonstrated the cleavage of the molecule of yeast nucleic acid into four mononucleotides under conditions of hydrolysis that are much milder than those employed by Thannhauser and Dorfmueller, yet it seemed desirable to prove that following the exact directions of these authors and employing efficient methods of separation one obtains in reality a mixture of mononucleotides and not a trinucleotide.

¹ Levene, P. A., *J. Biol. Chem.*, 1918, xxxiii, 425; 1919, xl, 415.

² Thannhauser, J. S., and Dorfmueller, G., *Z. physiol. Chem.*, 1917, c, 121.

The conditions of hydrolysis employed by Thannhauser and Dorfmueller were the following: 50.0 gm. of nucleic acid were taken up in 140.0 cc. of 25 per cent ammonia solution and boiled with reflux condenser for 2 hours. In the experiments herein reported 500.0 gm. of nucleic acid were taken up in 1,500 cc. of 25 per cent ammonia water and heated with reflux condenser for 30 minutes; thus the time of the action of the alkali was reduced to one-quarter of that employed in the original experiment of Thannhauser and Dorfmueller.

From the product of hydrolysis there were isolated in crystalline form the three mononucleotides entering into the structure of the molecule of nucleic acid and guanylic acid thus far obtained only in an amorphous condition.

These results were to be expected on the basis of the experience reported in previous publications, and they further confirm the conclusion regarding the structure of the molecule of yeast nucleic acid expressed by the present writer.

EXPERIMENTAL.

Conditions of hydrolysis were practically those of Thannhauser and Dorfmueller, save for the duration of the experiment. 500.0 gm. of nucleic acid were taken up in 1,500 cc. of 25 per cent ammonia water. The product of hydrolysis was concentrated under diminished pressure and separated into the guanylic and adenylic fractions following the directions of Jones and coworkers.³

Each fraction was converted into its brucine salt and these were fractionated by crystallization out of 35 per cent alcohol and out of methyl alcohol. The fractionation of this material did not proceed as smoothly as that of the material described in previous publications. As a guide the analysis of the brucine salts of various fractions was used. But the analytical differences of various fractions were not so characteristic as corresponding fractions of brucine salts, when these were obtained from material hydrolyzed under conditions described in previous papers.

³ Jones, W., and Richard, A. E., *J. Biol. Chem.*, 1914, xvii, 71. Jones, W., and Germann, H. C., *J. Biol. Chem.*, 1916, xxv, 93.

From the most soluble brucine salts (soluble in methyl alcohol) adenylic acid was obtained. The brucine salts were converted as usual into the lead salts and these into free adenosinphosphoric acid.

The analytical data on the substance are as follows:

0.1002 gm. of the substance gave 0.1190 gm. of CO_2 and 0.0418 gm. of H_2O .

0.2000 gm. of the substance employed for Kjeldahl nitrogen estimation gave 26.93 cc. of 0.1 N acid.

	Calculated for $\text{C}_{10}\text{H}_{14}\text{N}_4\text{P}_2\text{O}_7 + \text{H}_2\text{O}$ per cent	Found. per cent
C.....	32.86	32.39
H.....	4.41	4.67
N.....	19.16	18.85

The optical rotation of the substance was

$$[\alpha]_D^{20} = \frac{-0.84 \times 100}{1 \times 2} = -42.0^\circ$$

The mother liquor for the crystalline adenosinphosphoric acid on concentration gave a crystalline deposit resembling cytosinphosphoric acid. The substance was recrystallized out of a solution of one part of water to three of ethyl alcohol, and analyzed as follows:

0.1096 gm. of the substance gave 0.1360 gm. of CO_2 and 0.467 gm. of H_2O .

0.2000 gm. of the substance employed for Kjeldahl nitrogen estimation required for neutralization 18.87 cc. of 0.1 N acid.

	Calculated for $\text{C}_8\text{H}_{12}\text{N}_4\text{P}_2\text{O}_8$ per cent	Found. per cent
C.....	33.42	33.85
H.....	4.37	4.67
N.....	13.00	12.86

The rotation of the substance was

$$[\alpha]_D^{20} = \frac{+0.87 \times 100}{1 \times 2} = +43.5$$

The uridinphosphoric acid was obtained from the most insoluble fraction of brucine salts. The brucine salt was converted into ammonium salts. The sample, however, analyzed for a mixture of

mono- and di-basic ammonium salt. The mother liquor of the ammonium salt was transformed into a lead salt which, dissolved on boiling and on slow cooling, settled out in crystals of the appearance of the lead salt of uridinphosphoric acid.

The salt analyzed as follows:

0.1000 gm. of the substance employed for Kjeldahl nitrogen estimation required for neutralization 3.96 cc. of 0.1 N acid.

	Calculated for $C_8H_{11}N_2PO_6Pb$. <i>per cent</i>	Found. <i>per cent</i>
N.....	5.29	5.54

Guanosinphosphoric acid was obtained only in the gelatinous state, and only because of the small yield the material could not be made to crystallize.

RELATION OF HYDROGEN ION CONCENTRATION TO THE INCOAGULABILITY OF BLOOD PRODUCED BY PEPTONE, HIRUDIN, AND COBRA VENOM.*

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The experiments which form the basis of this paper were undertaken at the suggestion of Professor Mathews of this laboratory, with a view to determine, if possible, whether the processes giving rise to an inhibition of the coagulability of the blood through the agencies of peptone, hirudin, and cobra venom are accompanied by any alterations in the hydrogen ion content of the blood, and, if so, whether these changes might throw any light on the processes taking place. The results show that when incoagulability is produced by the intravenous injections of peptone, there occurs a very marked acidity which is absent when the incoagulability is brought about by similar injections of hirudin and cobra venom. Evidences adduced from experiments with the latter two substances indicate that their anticoagulant power is much diminished with an increase of acidity.

INTRODUCTION.

The properties of the three substances in question and their probable mode of action in the organism have been the subject of much experimental work. Many of these investigations have been made on animals of the most diverse types, and have given

* The work reported in this paper was done some time ago at the University of Chicago. The publication was delayed in the hope of adding to and elucidating some of the data. The intervention of the war delayed the publication still further.

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October, 1919.

rise to many contradictory statements and widely differing theories. However, since the results outlined in the following pages have been obtained from a study of dog blood only, and deal with the physicochemical conditions under which the peptone, hirudin, and venom act, or which they create in the blood, rather than the compounds with which they react, a review of the literature pertaining to these substances is not given.

Methods.

All estimations of the reaction of the blood were made by means of the gas chain method, and since the procedure adopted has been that described by Michaelis (1) in detail, no description of it will be given here. The electrode vessels used were the Michaelis U-tubes into which the blood was allowed to flow from cannulas inserted into the vessels of the animal. In the case of the ear veins the blood passed from an incision in the vessels directly into the hydrogen electrode. The readings obtained with these tubes were frequently supplemented by others made with the Hasselbalch electrode which gives slightly more nearly correct values when the fluids examined contain large quantities of CO_2 . Very small differences, practically negligible, were found between the values obtained with either electrode. This is probably due to the small percentage of CO_2 which the peptone blood contains, as has been shown by Salviolo (2) and by Lahousse (3). Unless otherwise mentioned, coagulation was considered complete when the tube containing clotted blood could be inverted without loss of contents. This method of estimating coagulation, although less exact than others, was employed because a minimum amount of time was required in manipulation. Throughout the series, dogs were used exclusively, and these were not fed for 24 hours preceding each experiment.

Further description of methods employed is given in connection with the various groups of experiments into which the paper is divided.

RESULTS AND DISCUSSION.

1. Experiments Showing Changes in Alkalinity Following Injection of Peptone.

Previous to each experiment the reaction of normal dog blood was estimated in blood obtained from the vessels of the ear. The dog was then anesthetized with ether and, during the anesthesia, cannulas were inserted into the external jugular vein and the carotid artery. The animal was then allowed to recover for 1 hour in order to avoid any possible alteration in reaction of the blood resulting from the anesthetic which has been shown by Menten and Crile (4) to cause a marked increase in acidity persisting for a period not longer than 45 minutes. On complete recovery, the required amount of 9 per cent Witte's peptone in 0.85 per cent NaCl was run into the jugular vein from a burette and duplicate samples of blood were then drawn immediately and subsequently at varying intervals from the carotid artery. One sample was observed for the coagulation time and on the other measurements of the alkalinity were made. Following the injection of the peptone in quantities greater than 0.1 gm. per kilo of dog, the blood rapidly develops a marked increase in acidity, of which the degree and the rapidity of onset are largely dependent upon the amount of peptone injected. The greater the percentage of peptone per kilo of animal, the more profound is the reaction and the more rapidly does a fatal acidity of the blood develop. This is illustrated by Protocols 1 and 2 which are typical of the five experiments made.

Protocol 1.—Dog weighed 5 kilos. 1 hour after cessation of ether administration 30 cc. of 9 per cent Witte's peptone in 0.85 per cent NaCl (0.54 gm. of peptone per kilo) were injected into the external jugular vein. Blood withdrawn from the carotid artery shows the values given in Table I. Normal blood clotted in $3\frac{1}{2}$ minutes, but all samples of peptone blood were uncoagulated at the end of 48 hours.

Protocol 2.—Dog weighed 4,400 gm. 1 hour and 10 minutes after the cessation of ether administration 95 cc. of 9 per cent Witte's peptone in 0.85 per cent NaCl (2.11 gm. per kilo) were rapidly injected into the external jugular vein. Samples of blood withdrawn from the carotid artery remained uncoagulated in the ice box at the end of a week and gave the reactions recorded in Table II.

TABLE I.

	Blood.	Blood $H^+ \times 10^{-7}$
	<i>pH</i>	
Normal blood from ear vein.....	7.41	0.39
3 min. after peptone injection.....	7.38	0.42
6 " " " "	7.33	0.47
8 " " " "	7.31	0.49
11 " " " "	7.19	0.65
15 " " " "	7.16	0.70
21 " " " "	7.14	0.73
26 " " " "	7.11	0.79
29 " " " "	7.09	0.82

TABLE II.

	Blood.	Blood $H^+ \times 10^{-7}$
	<i>pH</i>	
Normal blood from ear vessels.....	7.31	0.49
5 min. following peptone injection.....	7.09	0.82
7 " " " "	7.02	0.96
15 " " " "	6.94	1.16
17 " " " " Dog died.		

When a smaller amount of peptone was injected, the maximum acidity did not reach such a high value, and the blood in a short time regained its normal reaction, as is shown in Protocol 3.

Protocol 3.—Dog weighed 8,700 gm. Into a cannula in the external jugular vein 40 cc. of 8 per cent Witte's peptone in 0.85 per cent NaCl (0.37 gm. per kilo) were rapidly run from a burette. Blood from the carotid artery gave the reactions recorded in Table III.

TABLE III.

	Coagulation time.	Blood.	Blood $H^+ \times 10^{-7}$
		<i>pH</i>	
Normal blood from ear.....	3 min., 40 sec.	7.43	0.37
6 min. after injection of peptone.	Between 3 and 4 hrs.	7.46	0.35
9 " " " " " "	3 " 4 "	7.31	0.99
11 " " " " " "	4 " 5 "	7.27	0.54
14 " " " " " "	4 " 5 "	7.13	0.74
17 " " " " " "	4 " 5 "	7.15	0.70
19 " " " " " "	4 " 5 "	7.18	0.66
21 " " " " " "	15 min.	7.37	0.34

With doses of peptone less than 0.5 gm. per kilo of animal immediately following injection there is produced a suspension of coagulability parallel with which an increased acidity is developed in the blood. The period of time during which the coagulant power of the blood is suspended varies between 15 and 20 minutes, an observation already reported by Gley and Pachon (5) and other workers. At the end of this period there is a return to the normal blood reaction, with a loss of the acquired property of incoagulability.

TABLE IV.

	Coagulation time.	Blood	Blood $H^+ \times 10^{-7}$
		<i>pH</i>	
Normal blood from ear.....	3½ min.	7.44	0.37
“ “ “ “ during artificial respiration.....	3½ “	7.46	0.35
Blood taken			
4 min. after peptone injection.	Not coagulated in 5 hrs.	7.51	0.31
7 “ “ “ “	“ “ “ 5 “	7.34	0.46
10 “ “ “ “	“ “ “ 5 “	7.23	0.59
13 “ “ “ “	“ “ “ 5 “	7.22	0.61
18 “ “ “ “	“ “ “ 5 “	7.34	0.46
23 “ “ “ “	32 min.	7.34	0.46
30 “ “ “ “	5 “	7.38	0.42

In order to ascertain whether these changes were not primarily due to changes in respiration, experiments were performed in which, following severing of the spinal cord, artificial respiration was instituted so there could be no lack of respiratory exchange in the lung due to decreased oxygen tension in the alveoli. That the acidity is not due to this cause is clearly indicated by Protocol 4. Three similar experiments gave analogous results.

Protocol 4.—Dog weighing 8 kilos was anesthetized with ether and cannulas were inserted into the external jugular vein and carotid artery. The spinal cord was severed and artificial respiration commenced immediately. 10 minutes subsequently 31 cc. of 9 per cent Witte's peptone in 0.85 per cent NaCl (0.35 gm. of peptone per kilo) were injected into the external jugular. The blood gave the reactions recorded in Table IV.

Contejean (6) who in his experiments, previous to the injections of peptone severed the spinal cord for the purpose of exclud-

ing the possible influence of the nervous system on the retardation of coagulation caused by peptone, also reports no appreciable difference in the incoagulability obtained when this procedure was employed.

In order to ascertain whether there was developed in the plasma a rise in the acidity coincident with that occurring in the blood, a number of experiments were performed in which readings were made on both fluids. In the five experiments made the changes in the reaction of the plasma were also found to be marked as is shown in Protocol 5.

TABLE V.

	Blood.	Blood $H^+ \times 10^{-7}$.	Plasma.	Plasma $H^+ \times 10^{-7}$.
	<i>pH</i>		<i>pH</i>	
Normal blood from ear vessel.....	7.48	0.33	8.13	0.07
2 min. following peptone injection....	7.43	0.37	8.03	0.09
4 " " " "	7.40	0.40	7.96	0.11
8 " " " "	7.37	0.43	7.92	0.12
12 " " " "	7.32	0.48	7.89	0.13
15 " " " "	7.28	0.53	7.87	0.14
19 " " " "	7.22	0.61	7.84	0.15
23 " " " "	7.15	0.71	7.79	0.16
28 " " " "	7.09	0.82	7.75	0.18
35 " " " "	7.16	0.70	7.72	0.24

Protocol 5.—3 hours after the cessation of ether administration, there was injected into the external jugular of a dog weighing 8,500 gm. 40.7 cc. of Witte's peptone in 0.85 per cent NaCl (0.42 gm. per kilo). Measurements of the blood and plasma gave values which are typical of the five cases (Table V).

24 hours later, none of these samples was coagulated except the last in which small shreds of clot were beginning to form about the surface of the test-tube.

The experiments made with Witte's peptone demonstrate that coincident with the retardation or inhibition of coagulation, there is a marked increase in the acidity of the blood and of the plasma, and that this increase is proportional to the amount of peptone injected and the degree of incoagulability produced. These results on the change in acidity are in harmony with those reported by Salviole (2) and by Lahousse (3), both of whom

found by titration an increased acidity with a decreased CO_2 tension in the blood. Their observations were confirmed by the later publications of Athanasin and Carvallo (7) on this subject and are in direct opposition to those reported by Dastre and Floresco (8).

II. Experiments on Changes in Blood Reaction Caused by Injections of Peptone Subsequent to the Removal of the Liver.

That the liver plays an important rôle in the production of incoagulability with peptone has been shown by numerous observers. Contejean (9), Gley (10), Gley and Pachon (11), Delezenne (12), and Nolf (13) have demonstrated that removal of this organ from the circulation previous to injection of peptone solution prevents the development of incoagulability of the blood. With a view to determining whether the increased acidity which peptone develops with the liver intact could be duplicated in the animal from which the liver was removed, a number of experiments were performed. It is very difficult to remove the entire liver "en bloc" in a dog without occluding the vena cava. On this account each lobe was tied off separately as close as possible to the hilum of the liver with a wide tape. With even a considerable amount of the liver *in situ* with such doses as 0.35 gm. per kilo of animal, incoagulability does not occur and very little change in the blood is demonstrable; with doses as high as 0.7 gm. per kilo of animal a transient incoagulability may be produced with a simultaneous slight increase in acidity, which persists for a few minutes only. Injections were made in eleven animals from which the livers had been removed, and the results were as indicated in Protocol 6.

Protocol 6.—Dog weighed 7 kilos. During ether anesthesia, the lobes of the liver were tied off and cannulas were inserted in the external jugular vein and carotid artery. After the animal was allowed to recover from the anesthetic for 1½ hours, 42 cc. of 9 per cent Witte's peptone in 0.85 per cent NaCl (0.54 gm. per kilo) were injected into the jugular vein (Table VI).

The specimens in Table VI were kept fluid by the addition of hirudin which Michaelis (1) and subsequently others have shown to have no influence on the reaction of the whole blood.

The effect which is produced when small amounts of liver substance have been left in the animal after ligation of the lobes is illustrated by the values of the blood reaction obtained in a dog weighing 6,300 gm. which was given in a similar manner 0.60 gm. per kilo of a 9 per cent peptone solution in normal saline solution, 1½ hours after removal of the liver (Table VII).

TABLE VI.

	Coagulation time.	Blood.	Blood $H^+ \times 10^{-7}$
	min.	pH	
Normal blood from ear vein.....	4	7.42	0 37
“ “ “ “ “ after removal of liver.....	4	7.41	0.39
6 min. after peptone injection.....	5	7.38	0.42
8 “ “ “ “	5	7.37	0 43
12 “ “ “ “	6		
15 “ “ “ “	6	7.32	0 48
19 “ “ “ “	5	7.30	0 50
25 “ “ “ “	5	7.35	0.45
30 “ “ “ “	5	7.35	0.45

TABLE VII.

	Blood.	Blood $H^+ \times 10^{-7}$
	pH	
Normal blood after removal of liver.....	7.48	0 33
5 min. after peptone injection.....	7.36	0.44
10 “ “ “ “	7.25	0.57
13 “ “ “ “	7.25	0.57
16 “ “ “ “	7.25	0.57
20 “ “ “ “	7.24	0.53
30 “ “ “ “	7.25	0 57

All the above samples of peptone blood began to clot in 40 min.

In animals in which the liver had been removed for a period of more than 2 hours, an increased acidity developed without a corresponding retardation of coagulation. Protocol 7 is typical of this condition.

Protocol 7.—After the liver had been removed for 2 hours and 55 minutes from a dog weighing 8 kilos, 50 cc. of 9 per cent peptone in normal saline solution (0.56 gm. per kilo) were injected into the jugular vein. Values of blood reactions are recorded in Table VIII.

It is possible that this phenomenon is to be explained by the fact, first suggested by Contejean (6), that, while the greater part of the substance with which the peptone forms a direct combination is elaborated by the liver, other organs also produce this substance to a lesser degree. When the period of time following the extirpation of the liver is prolonged, an accumulation of this material can take place in these organs, or in the circulating fluid, in quantities sufficient to give on peptone injection a reaction approximating that obtained when the liver is intact.

TABLE VIII

	Coagulation time	Blood.	Blood $H^+ \times 10^{-7}$
	min.	pH	
Normal blood.....	3	7 40	0 40
“ “ after removal of liver.....	3	7.43	0.37
5 min. after peptone injection ...	10	7 14	0.73
10 “ “ “ “	10	7 15	0.71
15 “ “ “ “	12	7 13	0.75
19 “ “ “ “	12	7 12	0.77
21 “ “ “ “	12	7.12	0.77
26 “ “ “ “	12	7.10	0.81
35 “ “ “ “	13	7 07	0.86

III. Experiments on Changes in the Reaction of Peptone Subsequent to its Perfusion through the Liver.

As has already been mentioned, the fact that peptone owes its anticoagulant property primarily to the influence of the liver has been established by many investigators. By the interaction of two substances, one contained in the peptone and the other occurring in the liver, there is formed apparently a third compound which is the effective agent in the immediate production of incoagulability. None of these three compounds has yet been isolated, but their physiological properties have to some extent been studied, and especially that of the third in its relation to the prevention of coagulation extravascularly. The study undertaken by the writer was to investigate whether the interaction which takes place in the liver between the two substances mentioned would suffice to explain the reduction of alkalinity which accompanies the loss of coagulation, or whether the second

phase which is more directly concerned with the coagulation process itself was responsible for the change in the blood reaction. The first step was to obtain by means of the peptone perfusion through the liver a fluid which, when added to shed blood, retarded or prevented coagulation. The hydrogen ion concentration of the fluid was then measured. The perfusion experiments were performed on the liver *in situ*. For this purpose the animal was anesthetized and all vessels connected with the liver except the hepatic artery (or portal vein) and the descending vena cava below the liver were ligated. The fluid entering at either the portal vein or hepatic artery was passed through the liver and received again from the inferior vena cava into the perfusion apparatus through which it was kept circulating by means of a system of valves regulated by a motor. The whole apparatus was kept at a temperature of 38°C. by means of a water bath. Although attempts were made to maintain by means of an electric pad a normal body temperature in the animal, it rapidly lost heat. Solutions of 9 per cent Witte's peptone in 0.85 per cent NaCl with and without previously washing out the liver with Tyrode's, or normal saline, solution to render the organ blood-free were used through a series of experiments. Oxygenation of the peptone was secured by passing a continuous stream of oxygen through the fluid in the apparatus.¹

When the quantity of fluid perfused was large it was not possible to demonstrate that the perfusion fluid had acquired any anticoagulant properties during its passage through the liver. When added in concentrations as great as five parts of fluid to one of blood, there was no appreciable retardation of clotting. Further, no uniform results concerning changes in alkalinity were obtained in the five experiments made although the time during which the peptone was perfused varied from a few minutes to an hour.

Since the continuous perfusion of large amounts of peptone solutions (from 500 to 2,000 cc.) through the liver was unsuccessful in giving a fluid capable of diminishing the coagulation time, the expedient of passing small quantities of fluid separately through the liver and testing each for its anticoagulant power

¹ For the perfusion apparatus used I am indebted to Mr. Siegfried Maurer, who also very kindly helped me with the perfusion experiments.

was tried. The results of the five experiments performed are illustrated in Protocols 8 and 9.

Protocol 8.—In a dog weighing 5 kilos, the vessels of the liver, except the portal vein and the inferior vena cava below the liver, were tied. In each of these a cannula was placed and the liver washed out with 100 cc. of 0.85 per cent NaCl. This fluid possessed no anticoagulant property. 100 cc. of peptone solution were then perfused and, after passing through the liver, ten drops of this fluid added to 10 cc. of blood prevented coagulation for 5 hours. The value 0.168, 10^{-6} , which represented the acidity of the peptone solution was reduced to 0.21, 10^{-6} , after perfusion. A second 100 cc. of the same peptone solution possessed no anticoagulant action after its passage through the liver and gave a reaction of 0.42, 10^{-6} , at the end of the perfusion.

TABLE IX

Time after perfusion commenced	Amount of peptone fraction	Ratio blood peptone used for testing coagulation time	Coagulation time	Peptone	Peptone $H^+ \times 10^{-6}$
min	cc			pH	
2	20	1:1, 1:2, 1:3	Clots immediately.	6.73	1.90
4	20	1:1, 1:2, 1:3	Clots immediately.	6.73	1.90
6	10	1:1	1 hr.	6.70	2.02
16	10	1:1	1 "	6.65	2.26
26	10	1:1	10 min.	6.70	2.02
60	10	1:1	Clots immediately.	6.44	3.65
	(Expressed from liver.)	Peptone before perfusion.		6.80	1.60

Protocol 9.—Dog weighed 8 kilos. All the vessels supplying the liver, except the portal vein and inferior vena cava below the liver, were tied off. The 150 cc. of Tyrode's solution used to wash the blood out of the liver had no anticoagulant properties after its exit from that organ. 200 cc. of peptone were then injected into the portal vein, and after passing through the liver various fractions gave the reactions recorded in Table IX.

That the increased acidity coincident with the production of peptone incoagulability is not occasioned by that part of the process taking place in the liver is apparent from the figures in Table IX. One is, therefore, forced to conclude that this feature

of the phenomenon is intimately associated with those factors immediately concerned in coagulation. Control peptone perfusion experiments on kidney and spleen did not in any case result in the production of fluids possessing anticoagulant properties.

IV. Experiments on the Relation of the Hydrogen Ion Content and Hirudin in the Suspension of Coagulation.

The fact that the addition of hirudin to freshly shed blood in quantities sufficient to delay coagulation causes no appreciable change in the hydrogen ion content was first noted by Michaelis (1). Indeed, hirudin may be added in very considerable quantities to blood without any apparent influence on its reaction. The question, therefore, arose as to whether injection of this substance into the circulation would produce alterations in the

TABLE X.

	Blood	Blood $\text{H}^+ \times 10^{-7}$
	<i>pH</i>	
Normal blood from ear vein.....	7.50	0.32
3 min. after injection of hirudin.....	7.41	0.39
6 " " " " "	7.45	0.36
9 " " " " "	7.45	0.36
14 " " " " "	7.46	0.35
19 " " " " "	7.43	0.37
24 " " " " "	7.45	0.36
29 " " " " "	7.43	0.37
33 " " " " "	7.45	0.36

alkalinity of the blood similar in character to those obtained when peptone is injected, or would simulate those changes produced on inhibition of coagulation with hirudin *in vitro*.

Five experiments performed gave uniform results of which Protocol 10 is typical.

Protocol 10.—During ether anesthesia cannulas were placed in the external jugular vein and carotid artery of a dog weighing 5 kilos. 1 hour after the cessation of the ether administration, 200 mg. of hirudin in 50 cc. of 0.85 per cent NaCl were run into the jugular vein from a burette. Blood withdrawn from the carotid artery gave the reactions shown in Table X. Duplicate samples of blood remained unclotted at the end of 10 hours

TABLE XI.

M/16 Na ₂ HPO ₄		M/16 KH ₂ PO ₄		H ⁺ of solution.	Phosphate solution used.	Blood used.	Coagulation time.						
cc.	10.0	cc.	10.0	0.32, 10 ⁻⁴	cc.	5	I (0.0005 gm. hirudin).	II (0.0005 gm. hirudin)	III (0.001 gm. hirudin).	IV (0.0015 gm. hirudin).	V (0.002 gm. hirudin).	VI (0.005 gm. hirudin).	VII (no hirudin).
							20 min.	15 min.	2 min.	Immediately.	22 min.	Immediately.	16 min.*
0.1	9.9	1.14, 10 ⁻⁵	5	5	27 "	"	21 "	4 "	4 "	1 min.	22 "	2 min.	15.5 "
0.25	9.75	0.51, 10 ⁻⁵	5	5	36 "	"	34 "	5 "	5 "	3 "	2 "	3 "	15.5 "
0.5	9.5	2.58, 10 ⁻⁶	5	5	40 "	"	38 "	8 "	8 "	5 "	2 "	4 "	15 "
1.0	9.0	1.12, 10 ⁻⁶	5	5	44 "	"	39 "	10 "	10 "	8 "	2½ "	4 "	15 "
2.0	8.0	0.58, 10 ⁻⁶	5	5	46 "	"	42 "	14 "	11 "	3 "	3 "	4 "	12 "
3.0	7.0	0.34, 10 ⁻⁶	5	5	50 "	"	45 "	15 "	15 "	3 "	3 "	6 "	13 "
4.0	6.0	0.23, 10 ⁻⁶	5	5	53 "	"	50 "	17 "	15 "	4 "	4 "	7 "	10 "
5.0	5.0	1.54, 10 ⁻⁷	5	5	57 "	"	54 "	20 "	18 "	6 "	6 "	9 "	11 "
6.0	4.0	1.05, 10 ⁻⁷	5	5	1 hr.	"	59 "	27 "	22 "	9 "	9 "	9 "	5.5 "
7.0	3.0	0.68, 10 ⁻⁷	5	5	1 "	6 min.	1 hr.	36 "	26 "	13 "	13 "	14 "	4.5 "
8.0	2.0	0.42, 10 ⁻⁷	5	5	1 "	22 "	1 "	40 "	35 "	15 "	15 "	20 "	3.5 "
9.0	1.0	1.85, 10 ⁻⁸	5	5	1 "	50 "	1 "	51 "	40 "	31 "	31 "	35 "	3.5 "
9.5	0.5	0.91, 10 ⁻⁸	5	5	2 "	30 "	2 "	10 "	59 "	41 "	41 "	49 "	3.5 "
9.9	0.1	0.21, 10 ⁻⁸	5	5	3 "	20 "	3 "	15 min.	1 hr. 20 min.	56 "	1 hr.	1 hr.	3.5 "
10.0	0.0	6.58, 10 ⁻⁹	5	5	4 "	10 "	3 "	48 "	1 " 50 "	1 hr. 21 min.	1 " 30 min.	1 " 30 min.	3.5 "
Coagulation time of untreated blood.....							3 min.	3½ min.	3 min.	4 min.	3 min.	3 min.	3½ min.

* Clot does not become firm.

TABLE XII

0.1 N sodium acetate.		0.1 N acetic acid.	Distilled water.	H ⁺ of the acetate solution.	Acetate solution used.	Blood used.	Coagulation time									IX (0.005 gm. hirudin).
cc	cc.	cc	cc		cc	cc	I (0.0005 gm. hirudin).	II (0.0005 gm. hirudin).	III (0.001 gm. hirudin).	IV (0.0015 gm. hirudin).	V (0.0015 gm. hirudin).	VI (0.0015 gm. hirudin).	VII (0.002 gm. hirudin).	VIII (0.005 gm. hirudin).		
							min.	min.	min.	min	min	min	min.	min.		
1	0.1	8.90	2, 10 ⁻⁷	5	5	5	Coagulated within 3 min.	Coagulated in 3 min.	7	12	47	42	14	Uncoagulated.		
1	0.2	8.80	4, 10 ⁻⁷	5	5	5	"	"	6	9	37	27	12	Hemolysis.		
1	0.4	8.60	8, 10 ⁻⁷	5	5	5	Immediately.	Immediately.	5	7	30	21	9	20		
1	0.8	8.20	1.7, 10 ⁻⁶	5	5	5	"	"	5	5	27	18	7	14		
1	1.6	7.40	3.7, 10 ⁻⁶	5	5	5	"	"	3	4	16	17	6	11		
1	3.2	5.80	6.8, 10 ⁻⁶	5	5	5	"	"	3	3	15	15	5	8		
N acetic acid.																
1	0.64	8.36	1.3, 10 ⁻⁵	5	5	5	"	"	3	2	14	14.5	4	6		
1	1.28	7.72	2.6, 10 ⁻⁶	5	5	5	"	"	3	2	12	13	4	5		
1	2.56	6.44	5.2, 10 ⁻⁵	5	5	5	"	"	3	2	10	9.5	3	4		
1	5.12	4.88	1, 10 ⁻⁴	5	5	5	"	"	3	2	9	9	2	2		
Coagulation time of untreated blood.							3 min.	3 min.	3 min. 20 sec.	4	3	3	3 min., 20 sec.	4		
														3.0		

Measurements recorded in Table X show quite definitely that there is little increase in the acidity corresponding to the incoagulability which develops. Further, the small divergence of value of the reaction of the blood rendered incoagulable by hirudin from that of normal blood indicates the identity of the *in vivo* and *in vitro* action of this substance in the retardation of coagulation.

Since inhibition of coagulation with hirudin may occur with little change in the reaction of the blood, it may be questioned whether changes in the ionic concentration are a factor of any great significance in modifying the process. To test the possible influence of the hydrogen and hydroxy ion concentration on the anticoagulant action of hirudin equal amounts of Sørensen phosphate and acetate mixtures of known acidity and containing definite quantities of hirudin were added to shed blood, and variations in the coagulation time noted. The results of these experiments are given in Tables XI and XII.

The amount of hirudin specified at the beginning of each column denoting coagulation time represents the quantity of hirudin contained in the 10 cc. of blood mixture.

The marked influence of increased alkalinity in enhancing, and increased acidity in lessening, the action of hirudin in delaying coagulation is revealed by the values recorded in these two tables. Further, that other ions besides the hydrogen and hydroxy are of considerable importance in modifying the reaction is evidenced by a comparison of the coagulation time obtained when the acetate and phosphate mixtures used are of the same hydrogen ion concentration.

V. Experiments on Retardation of Coagulation by Cobra Venom.²

The first two of these experiments, outlined below, gave negative results because a quantity of venom insufficient to retard coagulation appreciably was used. In the first of these, a dog weighing 8,800 gm. received 2 cc. intravenously and 5 cc. subcutaneously of a 0.1 per cent solution in 0.85 per cent NaCl.

² For the cobra venom used in the five experiments made, I am indebted to Prof. Preston Keyes of this Laboratory, who most kindly supplied me with the material.

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The animal survived the injection $1\frac{1}{2}$ hours, but at no time was there any change in the coagulation time of the blood which also remained normal in reaction until a few minutes previous to death when the acidity became markedly increased. Similar results were obtained in a second dog weighing 4,400 gm. that received an injection of 2 cc. of 0.1 per cent venom in 0.85 per cent NaCl in the saphenous vein, and lived for 2 hours.

In the three experiments giving positive results, 10 cc. of 0.1 per cent venom in normal saline solution were injected. Each of these animals weighed between 5 and 6 kilos.

TABLE XIII.

	Coagulation time.	Blood. pH	Blood H ⁺ × 10 ⁻⁷ .
Blood withdrawn before anesthesia commenced	3 min., 20 sec.	7.40	0.40
3 min. following venom injection.	Not coagulated at end of 36 hrs.	7.41	0.39
4 " " " "	Not coagulated at end of 36 hrs.	7.38	0.42
6 " " " "	22 hrs.	7.35	0.45
8 " " " "	18 "	7.30	0.50
10 " " " "	Between 5 and 18 hrs.	7.25	0.57
12 " " " "	" 5 " 18 "	7.25	0.57
14 " " " "	5 hrs. 25 min.	7.22	0.61
16 " " " "	2 " 10 "	7.16	0.70
18 " " " "	1 hr. 8 "	7.08	0.84
20 " " " "	5 "	7.01	0.98
22 " " " "	Immediately.	6.93	1.18
23 " " " "			
Dog dying.			

As essentially the same results were obtained with the three animals, only one protocol is reported in detail.

Protocol 11.—Cannulas were inserted in the external jugular vein and the carotid artery of a fox terrier, weighing 3,500 gm., under ether anesthesia. The animal was allowed to recover from the anesthetic for 1 hour when 10 cc. of 0.1 per cent cobra venom were run into the jugular vein from a burette. The coagulation time and reaction of the blood drawn from the carotid immediately after and at varying intervals subsequent to the injection were as shown in Table XIII.

The blood withdrawn at 18, 20, 22, and 23 minutes after the venom injection had a very dark appearance, and this was especially marked in the blood sample with the most acid reaction.

The inimical influence of increased acidity of the blood on the inhibition of clotting by the use of cobra venom intravascularly seems to be established by the above results. As the amount of cobra venom necessary to inhibit extravascular clotting is comparatively large, a limited supply of the venom precluded any experiments on the relation between acidity and incoagulability developing *in vivo*.

VI. CONCLUSION.

From the work outlined in the preceding pages it is evident that the rôles which peptone on the one hand and hirudin and cobra venom on the other play in the prevention of retardation of clotting are of a very different character. With the production of incoagulability by peptone there occurs a marked increase in the acidity of the blood, a condition under which the other two substances lose completely or in large degree their anticoagulant power.

SUMMARY.

1. Coincident with the incoagulability of the blood produced by intravenous injections of Witte's peptone, there is a marked increase in the acidity of the blood and of the plasma.

2. When Witte's peptone is injected into the circulation subsequent to extirpation of the liver, extravascular clotting is not retarded, and the blood shows little change in acidity.

3. Witte's peptone which has acquired anticoagulant properties after perfusion through the liver shows only a slight increase in acidity.

4. The retardation of coagulation resulting from intravenous injection of hirudin is accompanied by little or no change in the acidity of the blood.

5. Increase of acidity of the blood lessens and increase of alkalinity enhances the property of hirudin in delaying clotting *in vitro*.

6. The reaction of the blood is little altered by intravenous injections of cobra venom in quantities sufficient to prevent clotting. With an increase of acidity of the blood its acquired incoagulability is lost.

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GAS PRODUCTION DURING THE ACETONE AND BUTYL ALCOHOL FERMENTATION OF STARCH.

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(Received for publication, July 3, 1920.)

In continuing an investigation of the production of acetone and butyl alcohol from starch, a detailed study has been made of the changes in the composition of the gas produced during the fermentation period. An attempt has also been made to coordinate the results from this and an earlier portion of the research (1), and to make a contribution to our knowledge of the biochemical mechanism of the fermentation as a whole.

Various observations regarding the composition of the gas formed during the production of butyl alcohol, alone or with acetone, have been recorded in the literature. Beijerinck (2) in his exhaustive study of *Bacillus butylicus* (*Granulobacter butylicum*) observed that H_2 and CO_2 are given off during the fermentation. Near the commencement the mean relative volumes of the gases were about 1 of CO_2 to 4 of H_2 . During the time of rapid cell division and butyl alcohol production the relation of the gases was 1 of CO_2 to 1 of H_2 . In some cases the percentage volume of H_2 in the gas was further reduced. In the so called "after-fermentation" the percentage volume of H_2 in the gas was found to increase. The organism investigated by Perdrrix (3), and named by him "*Bacille amylozyme*," was found to produce a diminishing amount of H_2 as the fermentation proceeded. It is of interest to observe that this organism also produces acetic acid and n butyric acid, the former in larger amounts at the beginning of the fermentation.

In his address on the fermentation of starch by the Weizmann organism Gill (4) stated that: "During the fermentation a mixture of approximately equal volumes of H_2 and CO_2 is evolved," and also, that: "When the fermentation begins, gas consisting of

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approximately equal volumes of CO_2 and H_2 is evolved." In their observations regarding the same fermentation Reilly and his collaborators (5) state that during the first half of the fermentation period the composition of the gas evolved changes, owing to a gradual increase in the CO_2 percentage. During the second half the composition remains constant and they attribute the earlier changes to the greater solubility of CO_2 in the medium.

Method.

The rates of various biochemical reactions of the fermentation have previously been observed and correlated, and in order to coordinate the changes in the composition of the gas with these reactions it is necessary to study the changes in relation to one of them. The rate of total gas production was arbitrarily chosen. It was then possible to correlate the observations with the formation of the acid and neutral products of the fermentation.

The rate of gas production was measured by means of the apparatus shown in Fig. 1. This can be assembled from the ordinary equipment of the laboratory and might be of value for class purposes owing to its cheapness and adaptability. The gas given off passes into the large test-tube through *A* and out again through *B*. The latter tube is drawn out to a capillary and in this way the flow of gas is restricted. The slight pressure created in the fermentation vessel is measured by means of the manometer in terms of a column of water. A trial fermentation is necessary in order to adjust the instrument. At the point of maximum gas production the capillary tip is carefully filed until a fairly large pressure is recorded on the manometer; *e.g.*, 8 inches. The rate of gas flow is proportional to the square root of the pressure, and comparative measurements are obtained which are sufficiently accurate for the purpose. If quantitative figures are required the instrument can be calibrated by placing it in series with a reliable experimental gas meter and a supply of gas.

Samples of gas were collected at regular intervals over mercury in the apparatus described by Harden, Thompson, and Young (6). During the early hours of the fermentation the O_2 , from the air still present in the vessel, was absorbed by phosphorus. Throughout the fermentation the CO_2 was absorbed by fresh KOH solution, and the H_2 was measured by difference.

The majority of the data collected was obtained from fermentations of 20 liters of mash containing 5 per cent maize meal.

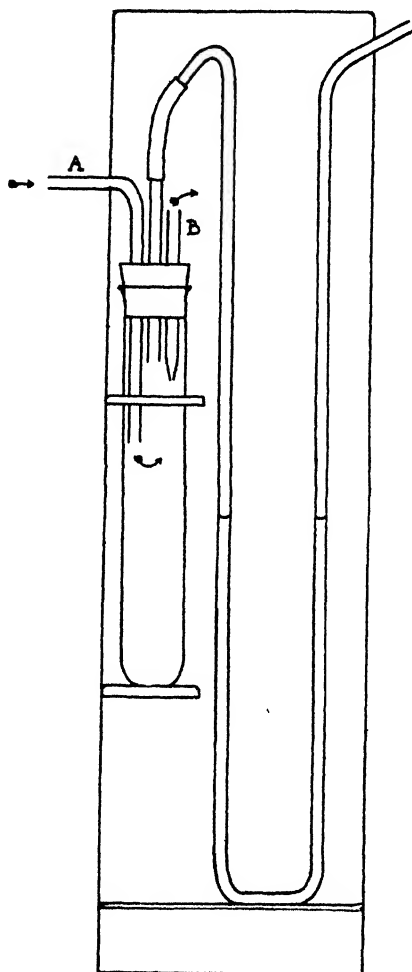


FIG. 1. The actual size of the test-tube is 9 by $1\frac{1}{2}$ inches, and the apparatus as a whole is drawn to scale.

They were conducted in suitably constructed copper vessels which were sterilized in a large autoclave. During the ferment-

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tation the vessel was placed in an incubator at 36°C., and a short tube passing through the door connected with the gas apparatus.

EXPERIMENTAL.

Series I.

Each experiment in the series was essentially the same and differed only in that a particular section of the fermentation period was under close observation. By standardizing the conditions as far as possible, a series of fermentations was obtained which differed only slightly in rapidity and total gas production. The results obtained are summarized in Table I, and are represented by curves in Fig. 2. The letters given to the periods of Table I and to the curves in Fig. 2 correspond. The various groups of figures for different periods overlap considerably, and from them it has been possible to construct a typical curve for the entire fermentation period.

Series II.

In connection with the observations on the early hours of the fermentation it was thought desirable, in view of their theoretical significance and the conclusions of other investigators regarding them, to discover if possible whether the gas actually produced during this period was in reality so rich in H_2 . There appeared to be a slight possibility that, owing to the gradual saturation of the medium with CO_2 , the gas evolved was not representative of the gas being produced.

A smaller volume of mash, 400 cc., was inoculated and allowed to ferment for 5 hours. The gas given off was collected over mercury. The gas in solution at the end of this period was expelled by heat and also collected. The gas produced during the 5 hours was found to contain 74 per cent of H_2 . Owing to the larger percentage of culture added to the mash this fermentation was more rapid than those of Series I.

It is considered justifiable therefore to conclude that, as the figures and curves suggest, the gas produced at the immediate commencement of the fermentation is pure H_2 . The percentage in the gas immediately begins to fall, due to the production with

TABLE I.

Period.	Date.	Time after inoc- ulation.	Pressure	\sqrt{P}	H ₂ in gas evolved.
	<i>1920</i>	<i>hrs.</i>	<i>in.</i>		<i>per cent</i>
A	Mar. 4, 8.00 p.m.	6	0.2	0.44	80.0
	9.00 "	7			76.0
	10.00 "	8			68.6
	<i>1918</i>				
B*	Mar. 13, 11.30 a.m.	6			71.0
	12.30 p.m.	7			58.5
	3.30 "	10			53.7
	6.30 "	13			46.2
	7.30 "	14			45.5
	8.30 "	15			40.8
	9.30 "	16			37.2
	<i>1920</i>				
C	Apr. 29, 10.00 a.m.	12	1.8	1.34	58.2
	11.00 "	13	1.8	1.34	55.8
	12.00 m.	14	1.8	1.34	54.6
	1.00 p.m.	15	1.9	1.37	53.0
	2.00 "	16	2.0	1.41	50.0
	3.00 "	17	1.8	1.34	49.5
	4.00 "	18	2.0	1.41	47.1
	5.00 "	19	2.3	1.51	44.2
D	Apr. 22, 11.30 a.m.	16			53.2
	12.30 p.m.	17			50.7
	2.30 "	19	1.9	1.37	45.0
	3.30 "	20	2.0	1.41	42.3
	4.30 "	21	2.6	1.61	39.5
	5.30 "	22	3.2	1.78	37.7
	7.30 "	24	5.0	2.23	33.4
	8.30 "	25	6.4	2.52	34.3
	9.30 "	26	6.9	2.62	35.8
	10.30 "	27	5.5	2.34	37.6
E	Apr. 30, 4.00 p.m.	26	5.3	2.31	37.5
	5.00 "	27	4.3	2.07	38.1
	7.00 "	29	2.7	1.64	40.4
	8.00 "	30	2.3	1.51	38.6

* These observations were made on a larger fermentation of 24,000 gallons of mash.

increasing rapidity of CO_2 . Beijerinck (2) does not speak of the composition of the gas produced at the start of the fermentation but of the total gas produced during the early hours of the fer-

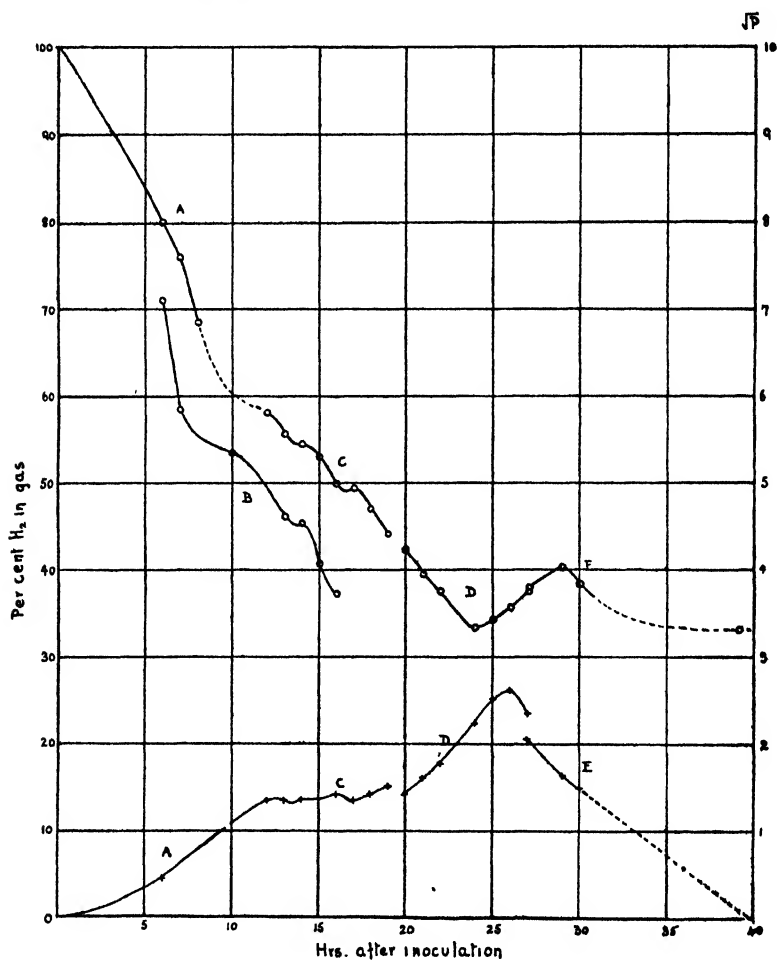


FIG. 2.

mentation. His observations could be made only at intervals of several hours owing to the fact that he was working with slower fermentations of small volumes of wort.

Further points of interest in the results obtained are as follows: After a period of about 5 hours the percentage of H_2 in the gas falls more rapidly during several hours, while during this time the rate of gas production is increasing. These changes are apparently brought about by the start or acceleration of some reaction by which CO_2 is produced. As we approach the period during which the acidity of the medium is at the maximum the composition of the gas does not change so rapidly. Furthermore it has been observed on numerous occasions that when, at the point of maximum acidity of the mash, the rate of gas production diminishes temporarily, the percentage of H_2 contained in the same remains constant or slightly increases. Attention is called to Section C of the curves in Fig. 2 which show clearly how on two occasions during the same fermentation these changes occurred. They are an indication of the complexity of the gas-producing system.

When the rate of gas production is once more increasing rapidly the percentage of H_2 in the gas falls at a uniform rate. Later, when the rates of production of acetone and butyl alcohol begin to diminish, and the rate of gas production is approaching its maximum, the amount of H_2 in the gas rises during 4 to 6 hours from 33 to 34 per cent to 38 to 40 per cent. Towards the close of the fermentation when gas production is falling rapidly to zero the percentage of H_2 in the gas falls once more. It would appear that just previous to the end of the fermentation the gas contains approximately 33 per cent.

Series III.

A number of experiments have been performed in order to determine the volume and composition of the total gas produced during the fermentation of a known weight of maize meal. A small volume of mash of known concentration was inoculated and allowed to ferment to completion in a water bath maintained at $36^\circ C$. The gas produced was collected and analyzed. It has been found that from 1 gm. of meal approximately 350 cc. of gas are produced, and that the gas is composed of 47.5 parts of H_2 and 52.5 parts of CO_2 by volume.

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The results from this investigation are in close agreement with those of Beijerinck for *Bacillus butylicus*; they differ in several important points from those of Gill (4) and Reilly and his collaborators (5) whose observations, as in the case of the writer's, were made on fermentations by the Weizmann organism.

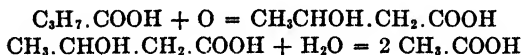
The Biochemistry of Acetone and Butyl Alcohol Production.

With the assistance of these results and those contained in an earlier communication (1) we shall now discuss briefly the biochemistry of the fermentation. Reilly and others (5) have recently presented in greater detail the view that acetone is formed from acetic acid. They consider that this is brought about by a condensation of the acid molecule with the production also of CO_2 and H_2O . It is shown that such a reaction is theoretically possible from the chemical standpoint and in accordance with certain experimental observations which have been made. The principal experimental evidence upon which this theory is based, namely the increase in the yield of acetone when acetic acid is added to the mash, when considered with observations made in this laboratory of the influence on the fermentation exerted by acids of the same series, requires, however, a different interpretation. Furthermore the results of different investigators have shown that the production of gas, H_2 and CO_2 , and the formation of acetone and butyl alcohol are intimately connected, and cannot be considered as entirely separate portions of the biochemical mechanism. The alcohols have been shown to be formed by the reduction of the corresponding acids, possibly by the addition of H_2 derived from some closely associated reaction. These facts appear to suggest that the formation of H_2 is closely connected with the production of acetone. It is felt that the scheme suggested by Reilly is weakened by the fact that acetone and butyl alcohol production have been considered apart from gas production, and as a result the source of H_2 has been relegated to some unknown associated reaction.

Newman (7) has recently brought forward a biochemical mechanism for the fermentation. He considers the first reaction to be the production of butyric acid from glucose in accordance with the following equation.



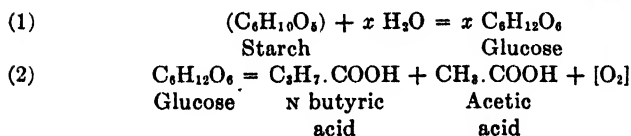
Acetic acid is then formed by the further oxidation of butyric acid:



Acetone is formed by the oxidation of butyric acid and butyl alcohol by its reduction.

The experimental results contained in this communication show that gas production at the commencement of the fermentation is not in accordance with Newman's first equation. His scheme necessitates a gradual fall in the H_2 content of the gas from an initial content of 50 per cent. Furthermore, the comparative evidence from the investigation of the oxalic acid fermentation of glucose by *Aspergillus niger* (8) and of xylose by silage bacteria (9) supports our earlier conclusion that the two organic acids are formed by oxidation and a break in the glucose molecule. It is also necessary to point out that Newman, in order to facilitate oxidation, introduces oxygen into his scheme without any indication as to its source. We are, however, considering the life processes of an organism which will not function in the presence of free oxygen, and consequently the essential problem is that of anaërobic respiration. Jost (10) has summarized earlier research and discussed in greater detail the nature of the problem.

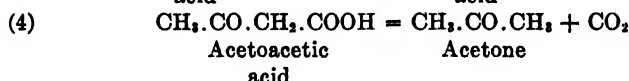
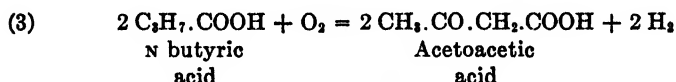
The following scheme is suggested as being in harmony with (a) experimental observations, (b) the requirements of the organism, and (c) the conditions obtaining during the fermentation. It has been previously shown that the first two stages of the fermentation may be represented by the following equations.



The oxygen produced during the second reaction cannot be detected by ordinary chemical methods and therefore must be used up in closely associated reactions by which oxidation is brought about. It has been shown that acetone production commences very early in the fermentation and previous to the

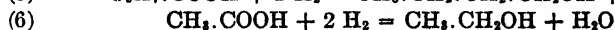
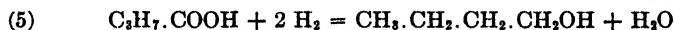
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start of butyl alcohol production (1). The gas given off at the commencement is pure H_2 , but immediately a gradual and increasing dilution by CO_2 occurs in the gas being produced. From this evidence we conclude that acetone is formed by the oxidation of butyric acid in accordance with the following equations.



Acetoacetic acid has not been identified in this laboratory, but owing to the nature of the biochemical system this failure to isolate one of several intermediate compounds does not rule out our interpretation of other experimental evidence. It is of interest to observe also that Raistrick and Clark (8) have recently stated that from unpublished results they conclude that acetoacetic acid is an intermediate compound in this fermentation. Attention also is called to the work of Witzemann (11) who has obtained acetone as a result of the β -oxidation of butyric acid by means of H_2O_2 .

The formation of butyl alcohol, and to a much smaller degree of ethyl alcohol, takes place by the reduction of the corresponding acid, in accordance with the following equations.



Apparently this reduction is not brought about by the activity of specific enzymes, owing to the fact that when propionic acid is added to the mash it is partially reduced to propyl alcohol (1).

It is necessary also to account for the following experimental data: (a) the disappearance of a larger amount of acetic acid than can be accounted for by the amount of ethyl alcohol produced during the fermentation; (b) the volume of H_2 and CO_2 given off which cannot be accounted for by the activity of reactions previously mentioned in this scheme; and (c) the consumption of $[O_2]$ made available by the production of butyric acid which is not further oxidized to acetone, but reduced to the alcohol. These

problems and the biochemistry of the postfermentation period are being investigated and will be considered in a further communication.

SUMMARY.

1. An investigation of the acetone and butyl alcohol fermentation of starch has been continued. Results are given of experiments in connection with the following problems.

(a) Changes in the composition of the gas produced during the fermentation period.

(b) The volume and composition of the gas produced by the fermentation of a known weight of maize.

2. The biochemical mechanism of the fermentation is discussed in the light of these results and those contained in an earlier communication.

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THE EFFECT OF WHOLE BLOOD TRANSFUSION ON THE CHOLESTEROL CONTENT OF HUMAN SERUM IN PERNICIOUS ANEMIA.

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(Received for publication, June 29, 1920.)

Among the substances which inhibit the hemolytic action of saponin (1-3), tetanolysin (4), pneumococcus hemotoxin (5), bile salts (6), and oleates (7, 8), cholesterol has been shown to assume a position of considerable importance. This general anti-hemolytic property of free cholesterol thereby derives for itself a close relation to the study of pernicious anemia, in which disease the marked reduction of erythrocytes and hemoglobin is of unknown etiology.

With the lowering of the red blood cell count and the hemoglobin in pernicious anemia, it has been demonstrated that cholesterol is also invariably lower than normal. Thus in three cases of pernicious anemia Csonka (9) found that the cholesterol content of the blood was lower than that of a normal individual. Bloor (10) reported that of twelve cases of pernicious anemia, the total cholesterol varied from 140 to 173 mg. averaging 156 mg. per 100 cc. of plasma. Like figures are reported by Denis (11), who also found an average of 156 mg. per 100 cc. of blood in twelve cases of this disease.

The cholesterol content of the erythrocytes is known to exist almost entirely in the free form (12), there being little or no cholesterol ester present. Since this free cholesterol as stated above, and not cholesterol ester, has been shown to possess the anti-hemolytic property, its presence in the corpuscles, as such, apparently constitutes an immediate and appropriate mechanism of protection against the hemolytic substances brought into contact with the corpuscles in the blood. A replenishing source of free cholesterol is present in the plasma, which normally contains 25 to 35 per cent

of the total cholesterol as free cholesterol (13). This free cholesterol is probably taken up by the corpuscles through the activity of their cholesterase (14).

It would seem desirable to determine the variation in the free cholesterol but since a normal relation is maintained in the plasma in pernicious anemia between the free and cholesterol ester (10), variations in the total cholesterol would indicate variations in the free form.

Because of the variation below normal of this antihemolytic substance in the blood of patients suffering from pernicious anemia, it was of particular interest to note the effect of the addition to the serum of the patient of a quantity of blood, the serum of which contained a much greater amount of cholesterol. Denis (11) has stated that in three cases markedly improved by blood transfusion the cholesterol content of the blood was not proportionately increased.

Through the courtesy of Dr. G. C. Weil of Mercy Hospital, a series of cases presenting the cardinal symptoms and signs of pernicious anemia was available for study. The blood pictures of these cases were those of pernicious anemia of severe grade with the typical alteration in the appearance of the erythrocytes, as well as the diminution of their number and corresponding reduction of hemoglobin percentage.

Blood was transfused directly by a modified Unger method. Blood from the recipient and donor was obtained immediately before, and from the recipient from 3 to 5 minutes after, transfusion.

The results of the analyses of the sera from these specimens of blood, using the method of Bloor (15) compared with the hemoglobin estimations and erythrocyte counts are shown in Table I.

In all these cases there is shown an increase in the total cholesterol content of the serum of the recipient following the transfusion. This increase varied from 5 to 34 mg. averaging 18 mg. per 100 cc. of serum. That the increase is only a temporary one is shown by the return of the cholesterol figure to approximately that immediately preceding the transfusion. The variability of the increase is probably dependent upon the degree of admixture of the blood of the donor with that of the recipient, and upon the

TABLE I.

Case No.	Date.	Blood examination.		Total cholesterol per 100 cc of serum.	Amount of whole blood transfused.
		Hemoglobin.	Erythrocytes.		
1	1920	per cent		mg.	cc.
	Jan. 26	48	1,960,000		
	" 30			R. B.* 181	
				R. A. 227	450
				D. B. 308	
	Feb. 1			R. B. 148	500
	" 11			R. B. 135	
				R. A. 168	500
				D. B. 308	
	" 20			R. B. 183	260
2	" 24	62	3,240,000		
	Mar. 8			R. B. 133	
				R. A. 145	400
				D. B. 333	
	" 11	65	3,750,000		
	Gradual marked improvement.				
	Jan. 20	40	1,320,000		
	" 26				500
	" 29	45	2,210,000		
	Feb. 2			R. B. 131	
				R. A. 148	400
				D. B. 250	
	" 6	60	2,290,000		
	" 9			R. B. 139	
				R. A. 185	340
				D. B. 297	
	" 17	68	3,950,000		
	" 18			R. A. 153	
				D. B. 227	340
	" 24	75	3,470,000		
	Mar. 3			R. B. 137	
				R. A. 138	500
				D. B. 268	
	" 11	78	3,650,000		
	Marked clinical improvement.				

* R. B., recipient before transfusion. R. A., recipient after transfusion. D. B., donor before transfusion.

TABLE I—Continued.

Case No.	Date.	Blood examination.		Total cholesterol per 100 cc. of serum.	Amount of whole blood transfused.
		Hemoglobin	Erythrocytes.		
3	1920	per cent		mg.	cc.
	Jan. 27	64	2,300,000	R. B. 193	
	Feb. 2			R. A. 227	500
				D. B. 423	
	" 7	68	3,000,000		
	" 17	50	1,410,000		
	" 20			R. B. 195	440
			R. A. 203		
			D. B. 273		
	" 24	55	2,370,000		
General condition improved.					
4	1919				
	Nov. 5	22	900,000		
	" 14			R. B. 123	
	" 18	55	1,810,000		
	" 28			R. B. 143	
	Dec. 1	62	2,680,000		
	" 9			R. B. 163	400
	" 11	65	2,330,000		
	" 17			R. B. 211	400
	1920				
	Jan. 9				320
	" 16				440
	" 19	80	3,440,000		
Marked improvement in general condition at this time.					
	Feb. 10	60	1,770,000		
	" 25			R. B. 130	
				R. A. 141	500
	" 28	48	2,240,000		
	Mar. 3			R. B. 133	
				R. A. 152	
	" 8	45	1,890,000		
	" 10			R. B. 129	
				R. A. 153	420
				D. B. 166	
	" 24	56	1,950,000		
	" 27			R. B. 124	
				R. A. 135	500
				D. B. 238	

TABLE I—Continued.

Case No.	Date.	Blood examination.		Total cholesterol per 100 cc. of serum	Amount of whole blood transfused.
		Hemoglobin.	Erythrocytes		
	1920	per cent		mg	cc.
4	Apr. 8	40	2,050,000		
	" 17	35	1,390,000		
	" 19			R. B. 93 R. A. 97 D. B. 227	500
	General condition continued improved.				
5	Jan. 24	40	1,310,000		
	" 28			R. B. 128	500
	Feb. 18			R. B. 139 R. A. 135 D. B. 403	500
	" 26	50	2,000,000		
	Mar. 8			R. B. 121 R. A. 138 D. B. 320	300
	" 24	53	1,280,000		
	Apr. 1				300
	" 12	30	1,240,000		
	" 13				400
	" 15	35	1,570,000		
	" 26				400
	May 7				460
	" 16				420
	" 26			R. B. 104 R. A. 142 D. B. 373	500
	" 27	48	2,780,000		
General condition remained fair.					
6	1919				
	Nov. 12	22	1,160,000		
	" 29	40	1,370,000	R. B. 123 R. A. 157	420
	Dec. 3	52	2,670,000		
	" 16			R. B. 140	400
7	" 17	65	2,780,000		
	1920				
	Mar. 23	45	1,720,000	R. B. 154 R. A. 153 D B 438	420

TABLE I—*Concluded.*

Case No.	Date.	Blood examination.		Total cholesterol per 100 cc. of serum.	Amount of whole blood transfused.
		Hemoglobin.	Erythrocytes.		
	1920	<i>per cent</i>		<i>mg.</i>	<i>cc.</i>
7	Apr. 1	50	2,120,000		
	" 6	47	1,850,000		
	" 7			R. B. 156	
				R. A. 150	400
				D. B. 240	
	" 19			R. B. 164	
				R. A. 166	540
				D. B. 231	
	May 1	45	1,710,000		
	" 6	35	1,800,000		
	" 17			R. B. 166	
				R. A. 182	400
				D. B. 183	
	" 24	32	1,690,000		
	" 27	33	1,370,000		
	June 4			R. B. 161	
				R. A. 187	400
				D. B. 250	
	June 11	Death. Pernicious anemia.			
8	Jan. 5				400
	" 8				500
	" 15	55	2,530,000		
	" 16				500
	" 20	63	2,690,000		
	" 28	70	2,450,000		
	" 30			R. B. 147	
				R. A. 152	500
				D. B. 347	
	Feb. 11			R. B. 173	
				R. A. 179	280
				D. B. 316	
	" 17	65	2,780,000		
	" 23			R. A. 128	
				D. B. 304	280
	Mar. 11	Death after a gradual increase in severity of symptoms.			

length of time which elapses before the sample of blood following the transfusion is taken for analysis from the vein of the recipient into which the blood has been infused.

In the first five cases which showed distinct clinical improvement following repeated transfusion, the cholesterol content of the serum was not progressively increased. On the other hand in those cases having a fatal termination the cholesterol content was not proportionately lowered and at times not at all.

In Case 4, the first series of isolated analyses, where blood specimens were taken before transfusion, a progressive increase is seen in the cholesterol content of the serum, paralleling a distinct improvement in the clinical condition of the patient and a marked increase in the red blood cell count and hemoglobin percentage. This single instance of a relative increase in the cholesterol content of the serum with distinct clinical improvement and marked increase in erythrocytes and hemoglobin, may have occurred at a time when the patient was enjoying a remission in the course of the disease. This improvement was continued, but a lapse of treatment for approximately 2 months during this period brought about a considerable turn for the worse in the blood picture, with a return of the cholesterol to the previous low figure. This would seem to indicate that there is a close relation between the cholesterol content of the serum and the erythrocyte content and hemoglobin percentage. This relation is further borne out by a study of the other cases which shows that, in all but Cases 1 and 2, the cholesterol content bears some relation to the blood picture in holding to a constant low level with the continued depression of the red blood cell count and the hemoglobin percentage.

It is interesting to note that in Cases 1 and 2, with a marked improvement in the blood picture and clinical condition, and in Case 4, with continued clinical improvement and a practically constant blood picture, the cholesterol content is even slightly lower, indicating perhaps an increased utilization of this substance against the toxic elements causing hemolysis in the disease.

CONCLUSIONS.

1. Repeated whole blood transfusion does not appreciably alter the total cholesterol content of the serum in pernicious anemia.

2. The immediate increase in cholesterol in the serum of the recipient, following transfusion of whole blood, is dependent upon the degree of admixture of the blood from the donor with that of the recipient and upon the time which has elapsed after the transfusion, when the specimen of blood from the recipient is obtained.

3. The cholesterol content of the serum varies relatively with the degree of anemia and the hemoglobin percentage of the blood.

4. The cholesterol level in the serum of patients with pernicious anemia may be an index of its utilization against hemolytic substances present in the body in this disease. The relative depression of cholesterol in the more severe cases indicates an increased demand for the neutralization of these toxic substances.

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USE OF SYNTHETIC DIETS IN THE GROWTH OF BABY CHICKS.*

A STUDY OF LEG WEAKNESS IN CHICKENS.

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PLATES 1 AND 2.

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In the rearing of baby chicks in confinement a difficulty serious and obscure in its etiology is the one characterized by poultrymen as "leg weakness." This trouble usually develops in 4 to 6 weeks after hatching, but we have seen it show itself 4 to 6 weeks later. The principal symptoms shown by the bird are first an unsteady gait, developing into difficulty of locomotion with a tendency to remain squatted a good part of the time; a pronounced ruffled condition of the feathers; an anemic condition of the wattles and comb; and a swelling of the leg joints, which is sometimes permanent. A loss of appetite accompanies these conditions and usually death follows suddenly. Postmortem examination has not revealed any pronounced and characteristic changes. With some individuals there is compaction of the feces in the cecum, while with the others the cecum content is fluid and gassy. These latter observations may be related to the postmortem time of examination. With some individuals the liver was found abnormal in color, being pale yellow, but this condition was not found in all birds suffering from leg weakness and should not be considered an invariable occurrence.

Poultrymen have explained leg weakness as due to lack of exercise, overfeeding, or absence of green feed, and their remedy

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has been to feed light, provide a suitable scratch, and if possible feed some green feed. These practices will generally lead to an eradication of this trouble, but just which factor is the primary one in effecting a cure has not been clearly defined.

Drummond¹ experienced trouble in the use of the baby chick as an experimental animal in confinement. He believed that they could not be reared under such conditions, or at least expressed the view that there were very special conditions necessary for such rearing and not understood at the time when he wrote. Funk² was also familiar with the difficulties experienced in rearing baby chicks at all seasons of the year and under laboratory conditions. Osborne and Mendel,³ in attempts to use the chicken as an experimental laboratory animal, experienced similar difficulties with leg weakness. They succeeded, however, in rearing a number of chickens taken either at hatching time or at 3 weeks of age on a ration of natural materials, but which was fortified with a plentiful supply of roughage in the form of paper pulp. The rations were varied, but corn gluten, cotton-seed flour, soy bean flour, casein, protein-free milk, butter fat, starch, lard, and ferric citrate entered into the diet.

This observation, involving the recognition of the very great importance of a roughage factor in the diet of baby chicks, confirms our own experience in work with this animal under confinement and we believe may be taken as directly responsible for the prevention of leg weakness in chickens. We have worked with a variety of roughages, some of which were potent as protectives while others were not. Suspicion that this trouble in chickens might be scurvy led us to use orange juice in a number of cases as a curative, but the results were too varied and too distinctly negative to warrant the idea of a similarity in etiology between leg weakness and scurvy. The entire trend of our work is in confirmation of the observations of Osborne and Mendel that leg weakness is related to overfeeding, with a low amount of indigestible ballast in the ration and not to a lack of green feeds, exercise, outdoor air, or excessive feeding directly. Undoubtedly the latter is effective in hastening the development of

¹ Drummond, J. C., *Biochem. J.*, 1916, x, 77.

² Funk, C., *J. Biol. Chem.*, 1916, xxvii, 3.

³ Osborne, T. B., and Mendel, L. B., *J. Biol. Chem.*, 1918, xxxiii, 433.

leg weakness, because in the presence of plenty of roughage excessive feeding cannot take place. Possibly green feeds with their abundant supply of vitamins and some roughage are an unconscious cure of a sluggish intestine, but the same results can be obtained with an inert ballast such as paper, dirt, or charcoal.

EXPERIMENTAL.

As early as 1917 we began a study of the nutritive factors involved in the rearing of baby chicks. We used synthetic rations such as had been successfully employed in the rearing of the rat. With a ration composed of 18 parts of casein, 69.3 of dextrin, 5 of butter fat, 3.7 of salts, 2 of agar, and 2 of yeast there was complete failure in growth with the baby chick. On this ration a rat could be successfully reared. In all our experiments the casein was purified; the yeast was in dried powder form procured from a commercial brewing company; the butter fat was purified as customary for incorporation in the ration of purified food materials; the salt mixture consisted of

	gm.
NaCl.....	0.173
MgSO ₄ (anhydrous).....	0.266
NaH ₂ PO ₄ ·H ₂ O.....	0.347
K ₂ HPO ₄	0.954
CaH ₄ (PO ₄) ₂ ·H ₂ O.....	0.540
Iron citrate.....	0.118
Ca lactate.....	1.300
KI.....	Trace.

Started on this ration directly after hatching and at 39 to 40 gm. weight, baby chicks would grow for a short time, that is up to 50 or 60 gm., but would soon begin to lose weight and death would follow at the end of 3 to 5 weeks. Even increasing the yeast in the ration to 4 per cent thereby providing more water-soluble vitamin did not materially improve the ration. These animals had been on a shavings litter and had received limestone grits in a separate dish. Their rations had been fed as a mash and distilled water was always used.

In a later series of experiments where we used a synthetic ration such as described above, but more liberal in its content of butter fat (10 per cent) and yeast (5 per cent) and where the

animals had the run of a cut wheat straw litter, much better growth of baby chicks for 5 to 6 weeks was secured, but leg weakness soon developed and terminated the experiment. When the ration, undiluted with roughage, is fed as a mash there is no guarantee that chicks will eat enough straw provided by a cut straw litter to protect themselves fully against leg weakness.

In another series of observations, always involving six chicks in each experiment, we increased the butter fat to 15 per cent and

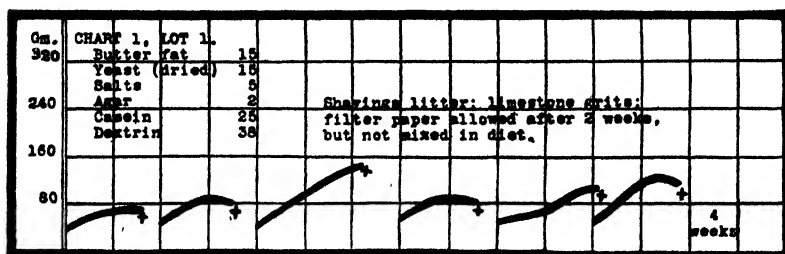


CHART 1. By merely presenting torn up filter paper to these baby chicks the development of leg weakness was not prevented. They ate some of the paper.

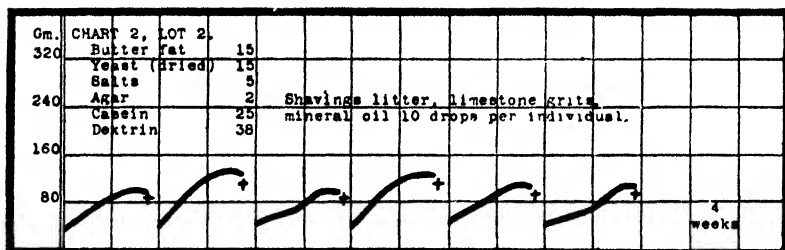


CHART 2. Mineral oil was without effect in preventing the development of leg weakness in chickens.

the yeast to 15 per cent of the ration. In all our experiments either Rhode Island Reds or White Leghorns were used. The ration was fed dry and as a mash with limestone grits. The litter was from shavings. After 2 weeks of this ration several additions were made in the hope of warding off leg weakness. In one case we added filter paper (see Chart 1). The paper was torn up by hand and thrown into the cage, but not incorporated in the diet. They ate some of it, but not enough to prevent

trouble. To another group (Chart 2) we gave mineral oil daily, at the rate of 10 drops per individual. This treatment was without effect. In Chart 3 are shown the results where the laxative, phenolphthalein, was used at the rate of 0.01 per cent of the ration. This addition gave no beneficial reaction and no better results than were secured by the use of mineral oil. Hull and Rettger⁴ had reported the successful use of lactose as a means of reducing putrefaction in the intestine of the rat with a change in

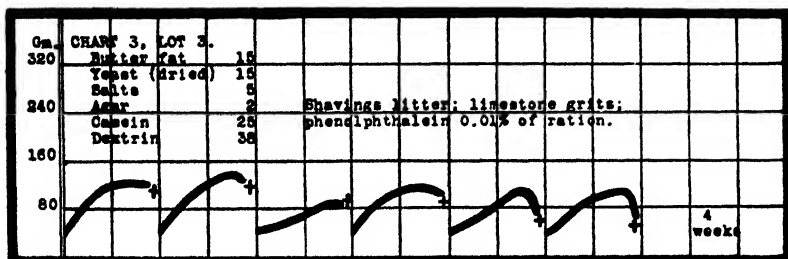


CHART 3. The use of phenolphthalein, a laxative, was not a successful measure for the prevention of leg weakness.

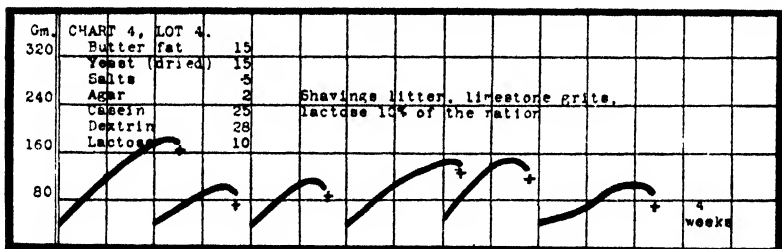


CHART 4. Lactose as 10 per cent of the ration did not prevent the development of leg weakness.

the character of the intestinal flora. If leg weakness is associated with a sluggish intestine and slow removal of waste then the possibility of curative results from the use of lactose is apparent. We incorporated this sugar in the ration at the rate of 10 per cent. In the concentration used it had no preventive effect on the development of leg weakness (see Chart 4).

⁴ Hull, T. G., and Rettger, L., *J. Bacteriol.*, 1917, ii, 47.

It had occurred to us that leg weakness might be "scurvy of chickens" and therein might rest the reasons for the successful use of green feed so generally advocated by all poultrymen. With this possibility in view we gave one lot of baby chicks, after they had been on the synthetic ration for 2 weeks, a daily allowance of crushed green cabbage leaves (Chart 5). They ate this material eagerly and probably consumed as much as would be expected from a bird of this size when allowed green materials under practical conditions. We had no better success with this lot than with those already described. This result in itself would strongly indicate that we were not dealing in the case of leg weakness with scurvy in chickens. Further confirmation of this view is afforded in later work herein reported where we administered daily the

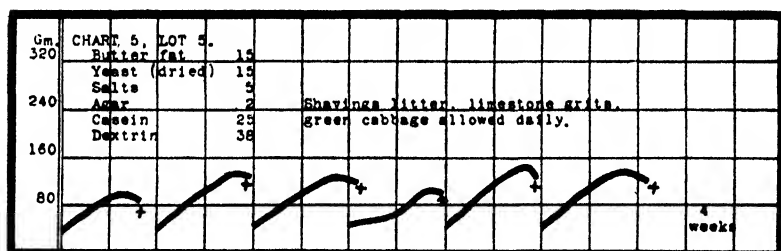


CHART 5. Green cabbage given daily did not ward off the development of leg weakness. This is a potent antiscorbutic and these results indicate that scurvy and leg weakness in chickens have not the same etiology.

classical antiscorbutic, namely orange juice, to a number of lots of chickens developing leg weakness, but without effecting cures. Possibly we delayed the termination of life by its use, but did not bring about such cures as can be accomplished with a guinea pig already seriously afflicted with the disease of scurvy.

In Chart 6 are shown the results of a direct attempt to cure leg weakness with a potent antiscorbutic, such as orange juice. Its administration daily in 1 cc. portions is a larger allowance per unit of live weight than has been used in the successful treatment of guinea pigs afflicted with scurvy. All this lot came down with leg weakness and continued to suffer from this affliction, although there was a much greater prolongation of the span of life by the use of orange juice. We never succeeded in effect-

ing complete cures or warding off the development of leg weakness by the use of orange juice when used at the rate of 1 cc. daily per individual. Further, the very fact that we finally succeeded in rearing to maturity birds whose diet was adequately diluted with some inert ballast is positive proof that we are not dealing with scurvy. In earlier work⁵ with chickens, restricted to grains fortified with inorganic salts, we observed slow growth and normal maintenance for 8 months, when the experiment was terminated. These results are given as further evidence that the chicken is not supersensitive to a low antiscorbutic vitamin ingestion as is the case with the guinea pig.

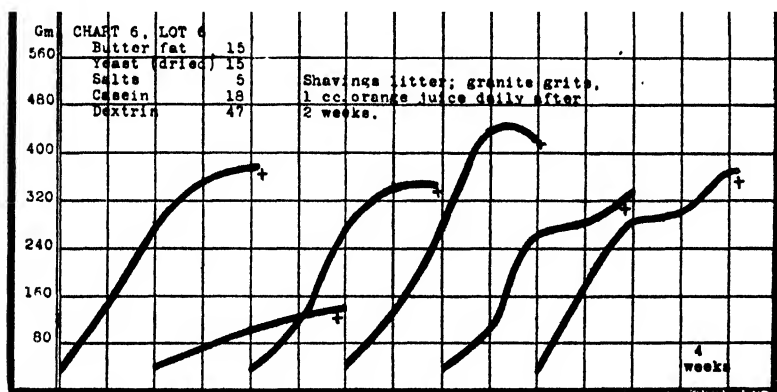


CHART 6. Leg weakness is not scurvy. Orange juice at the rate of 1 cc. daily per individual delayed death, but did not prevent the comparatively early termination of life of this group with leg weakness.

We next began a systematic study of the influence of inert materials as roughages in the ration with special attention to their nature as well as their quantity. An interesting failure is shown in Chart 7 where we used 10 per cent of filter paper in the ration. In this case the mixed nutrients were hand-mixed with the finely rasped paper. The mixture of paper and ration was not intimate enough to prevent picking out by the birds. They picked out the food ingredients leaving behind the paper. Leg

⁵ Hart, E. B., Halpin, J. G., and McCollum, E. V., *J. Biol. Chem.*, 1917, xxix, 57. Hart, E. B., Halpin, J. G., and Steenbock, H., *J. Biol. Chem.*, 1917. xxxi, 415.

weakness developed after 5 weeks restriction to this diet. After this group developed leg weakness we began the daily administration of orange juice but without curative effects. Contrast these results with those shown in Chart 12 where the paper was reground with the ration and where no orange juice was added. In this case complete success in rearing was attained.

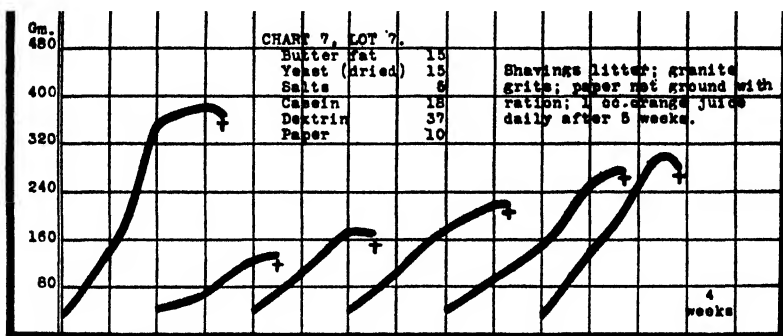


CHART 7. Paper mixed but not ground with the ration did not prevent the development of leg weakness. The birds did not eat enough of the paper. Administration of orange juice showed no remedial effects.

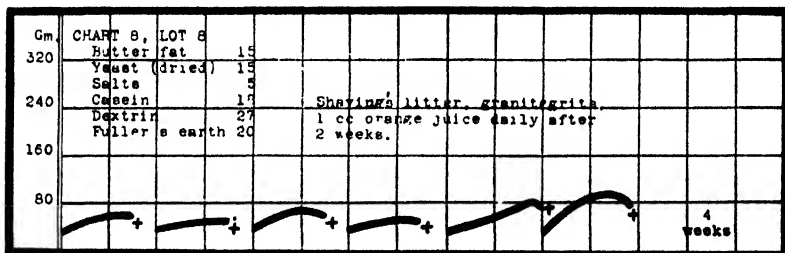


CHART 8. Fuller's earth is not a good roughage for baby chicks. Orange juice, a potent antiscorbutic, was of no help in preventing early death of the individuals in this lot.

We found fuller's earth a decidedly ineffective ballast. This colloidal siliceous material, used as 20 per cent of the diet, seemed to hasten the downward path of this group of birds. The results are shown in Chart 8. Shavings were used as litter and undoubtedly the chickens consumed some of this material, although not enough to act as an efficient protection against leg weakness.

After 2 weeks on the ration we gave orange juice at the rate of 1 cc. daily per individual, but without any help.

When we incorporated 20 per cent of charcoal in the ration with shavings as a litter we met with varied success (Chart 9). Three of the birds developed leg weakness, while three grew well, avoiding all trouble from this disease and reaching weights of 1,240, 706, and 805 gm., respectively, before being discarded. They were apparently normal in every respect. Just why we had mixed results is impossible to state, but there is a very considerable individual variation in chickens, making their use for nutrition work less satisfactory than the rat.

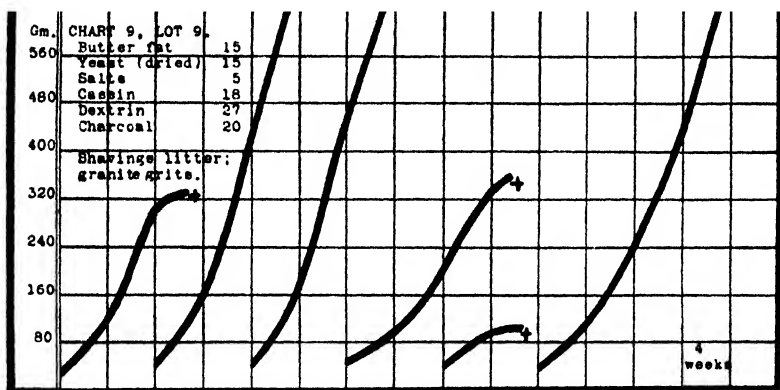


CHART 9. Charcoal was an effective roughage, but did not give us unqualified success.

The practice of turning baby chicks out on fresh upturned and unfrozen ground just as early after hatching as possible, with the time of hatching purposely regulated with reference to spring weather in order that this condition may be satisfied, is followed by poultrymen. The birds undoubtedly eat a considerable amount of this dirt; but that it is a nutritive factor of primary importance in their rearing is open to careful consideration. We incorporated into our synthetic ration 20 per cent of an air-dried garden soil and one not particularly rich in organic matter. The results can be seen in Chart 10. Two of the birds grew normally and reached weights of 1,380 and 995 gm. respectively, when discarded. They were apparently normal in every respect. Four

of the chickens in this lot did not grow well, developed leg weakness, and died at the end of 6 to 12 weeks. Orange juice was given these birds at the appearance of symptoms of leg weakness, but did not save them from an early death. It is possible that the amount of dirt fed was not well chosen for the reason that in later experiments we practically duplicated the above experiments by the use of 20 per cent of dirt on a sand litter, but had very much better success when we used but 10 per cent of dirt (*cf.* Charts 19 and 20).

All the experiments described above were conducted on shavings litter. We believe that this factor might have been the

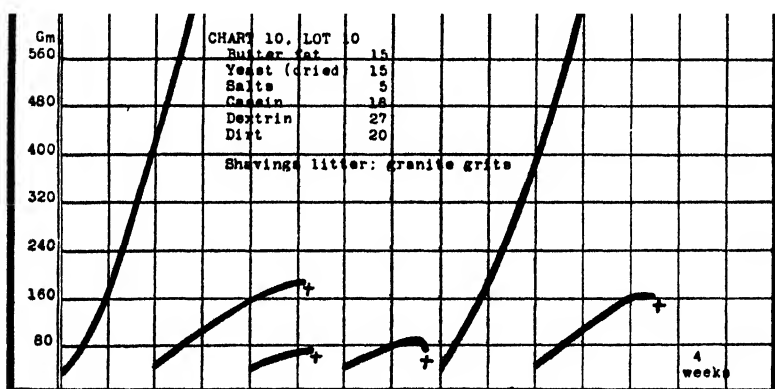


CHART 10. Dirt also was an effective roughage in some cases, but not of general success with the synthetic diet.

cause of the pronounced individual variation seen in our results. It was possible that some birds ate more of the shavings than others and thereby escaped the trouble of leg weakness. Accordingly we adopted sand as the litter, using the same synthetic rations as used in the earlier lots, whose curves of growth are displayed in Charts 6 to 10 inclusive. In these later experiments they may have eaten some of the sand, but its crystalline character as contrasted with the colloidal nature of shavings (cellulose, etc.) would probably make it very much less a disturbing factor than the shavings litter.

The rations were always fed dry or as a mash with distilled water and granite grits; they were never fed as scratch. The

roughage materials used were in the proportion of 10 or 20 per cent of the ration, although in the case of paper the maximum amount incorporated was 10 per cent and the minimum 5 per cent of the ration. The results secured with these rations are shown

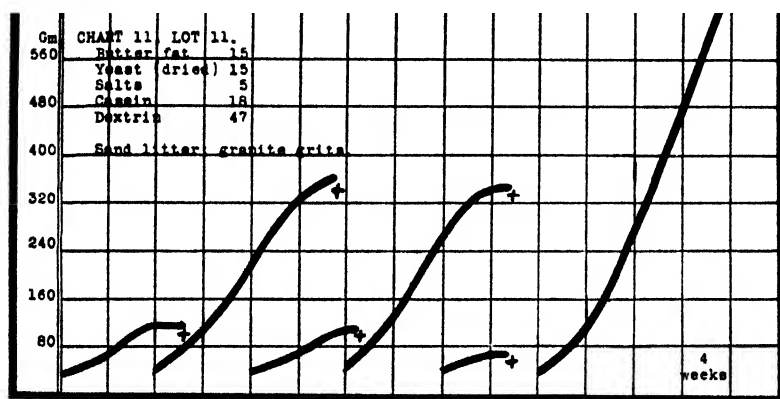


CHART 11. On sand litter and no roughage all the birds but one developed leg weakness.

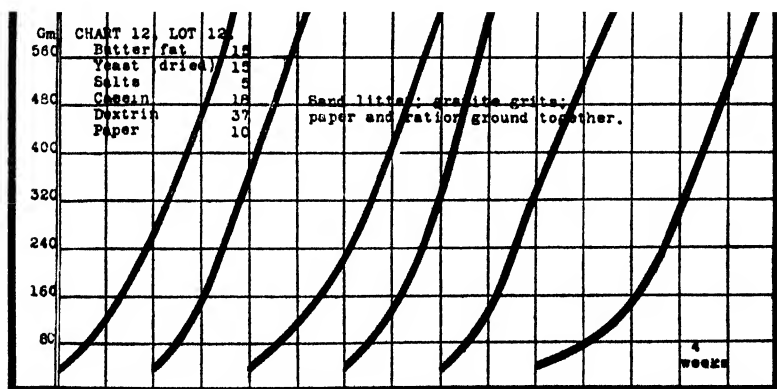


CHART 12. With 10 per cent of paper ground with the ration our most successful rearing of baby chicks on a synthetic diet was accomplished.

in Charts 11 to 20 inclusive. One group of chicks, Chart 11, was fed our synthetic ration, to which, however, no roughage was added. Five of the six individuals in this lot succumbed to leg weakness, but curiously enough one animal grew well, and did not develop

this trouble, reaching a weight of 880 gm. at the end of 18 weeks, when it was discarded.

Our most successful rearing is shown in Chart 12. With 10 per cent of paper finely comminuted and ground with the ration every chick in this group grew at a nearly normal rate and remained physically sound. The weights at the end of 16 weeks varied from 480 to 710 gm., respectively. They were apparently normal when discarded at the end of 18 weeks. These results we think disclose in a qualitative way the factors necessary in the rearing of baby chicks. The quantitative relation of these factors is still to be studied. When but 5 per cent of paper

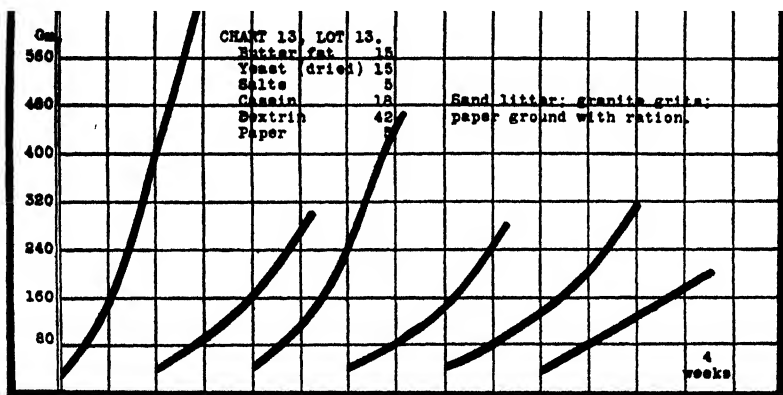


CHART 13. With 5 per cent of paper ground with the ration we were less successful than when 10 per cent was used. However, no leg weakness developed.

(Chart 13) was incorporated with the ration we did not attain the same measure of success as when 10 per cent was used. No leg weakness developed, but the rate of growth in all cases but one was slow. One bird reached a weight of 1,150 gm. at the end of 18 weeks, when the experiment was discontinued.

It is remarkable how great was the influence of the character of the ballast in these experiments. When we used 20 per cent of agar (Chart 14) in the ration, growth was practically suspended after 4 weeks and the span of life was greatly reduced. These birds showed a peculiar pulpy condition of the tissue, dropsical in character. By reducing the proportion of agar in

the ration to 10 per cent, better growth was attained than by the use of 20 per cent, although it was far below the success reached with paper, dirt, or charcoal. Three individuals from this group died from unknown causes, while the other three, all in poor condition, were discarded at the end of 13 weeks (Chart 15). None of this group had developed typical leg weakness.

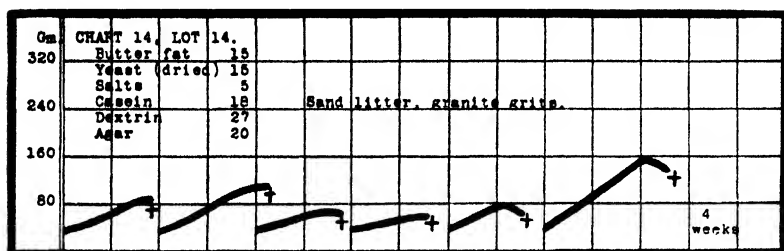


CHART 14. On a sand litter 20 per cent of agar was ineffective as a preventive of early death with the synthetic diet.

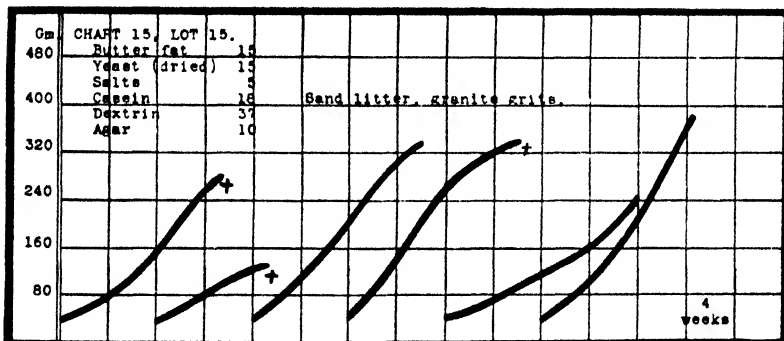


CHART 15. 10 per cent of agar gave better results than 20 per cent, but not complete success.

With 20 per cent of fullers' earth as the roughage (Chart 16) growth was subnormal and death followed early in life. This group did not develop the characteristic symptoms of leg weakness. Their appetites were enormous and their consumption records show a larger consumption of food at the end of 4 weeks than in the case of those fed the paper pulp ration (Chart 12). Probably the food was moving too rapidly through the intestine for maximum digestion and absorption.

With the sand litter and 20 per cent of charcoal (Chart 17) four of the birds grew well, reaching weights varying from 550 to 860 gm. at the end of 18 weeks, at which time they were discarded. Two birds from this group died from unknown causes, but none developed typical leg weakness. With 10 per cent of charcoal (Chart 18) the mortality was higher than where we used

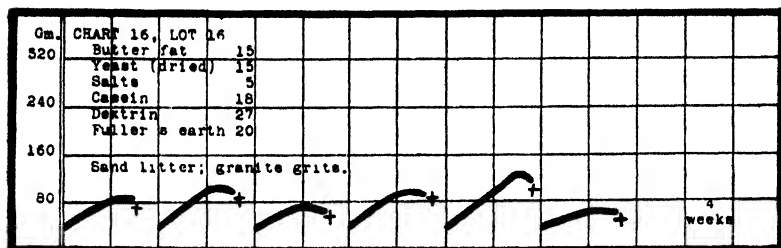


CHART 16. Fullers' earth at the rate of 20 per cent in the ration was absolutely ineffective as a preventive of early death in this group of chicks.

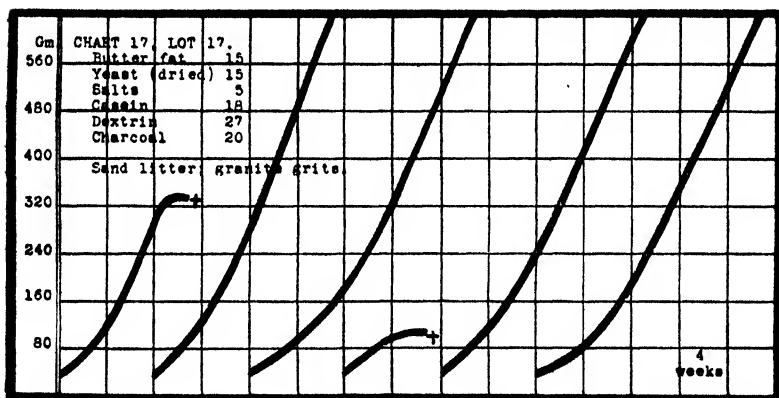


CHART 17. Charcoal at the rate of 20 per cent of the ration was less effective than 10 per cent of paper. No leg weakness developed in this group.

the higher level of 20 per cent. Two of the group reached weights of 710 and 740 gm. at the end of 18 weeks, two others grew at a much slower rate and were discarded at the end of 14 and 18 weeks respectively, while the remaining pair died at the end of 10 weeks. The cause of death was unknown, but it was not from leg weakness, with the usual symptoms.

When 20 per cent of dirt was incorporated with the ration, using the same soil as was used in our earlier experiments, we were unsuccessful in bringing any of the lot through to maturity (Chart 19). These animals did not develop typical leg weak-

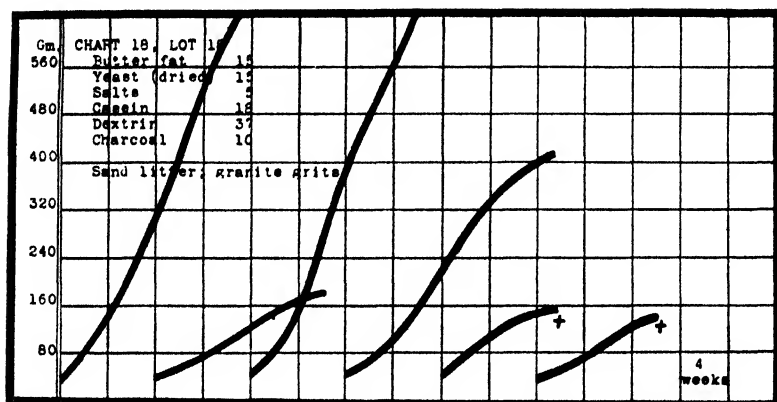


CHART 18. 10 per cent of charcoal in the ration did not lead to successful growth with all individuals, but none in the group developed leg weakness.

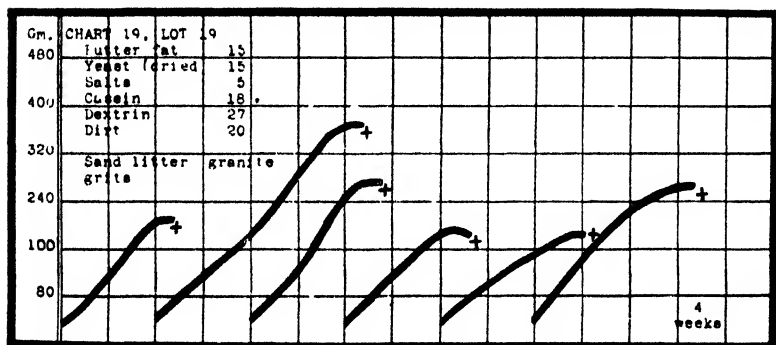


CHART 19. With 20 per cent of soil as a roughage we were unsuccessful in bringing any of the birds through to maturity.

ness, in so far as inability to walk is characteristic of that trouble, but they did show the ruffled feathers and swollen joints which are always part of the picture of leg weakness. With less dirt in the ration, 10 per cent, we were much more successful

in the rearing than where the higher level was used. Complete success was not obtained in this case (Chart 20) but four of the birds reached weights of 480 to 690 gm., respectively, in 18 weeks when they were discarded. Two from this lot died in the course of the experiment, but not from leg weakness. It is apparent that dirt itself is an effective factor in the rearing of baby chicks where the choice of the amount to be consumed is left to the bird. With a synthetic diet and under confinement the dirt was not so successful a source of ballast as was paper or charcoal.

It has been fairly well demonstrated by the work detailed above that the roughage factor when of suitable kind is the

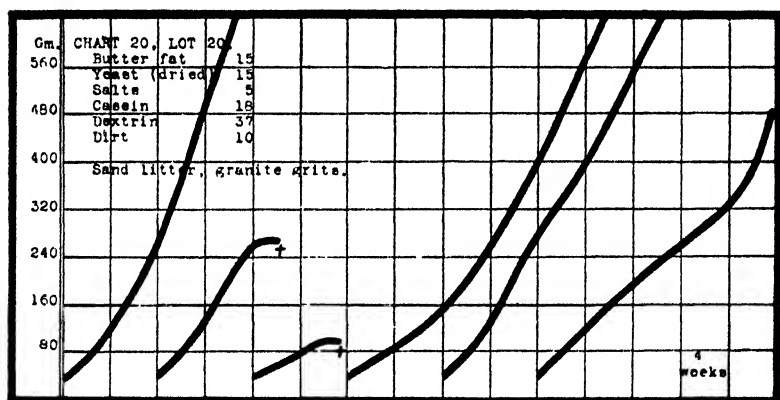


CHART 20. Incorporation of 10 per cent of soil was more effective than 20 per cent of the same material.

important one in preventing leg weakness. This malady is not due to a deficiency in one or more of the now recognized factors for successful nutrition such as energy, protein, salts, or vitamins or to a deficiency in supply of a special vitamin. Further demonstration of this fact is illustrated in Chart 21, where there was not only an abundant allowance of all the nutritive factors known at the present time, but where the exercise factor was also amply provided for. We used as scratch a grain mixture of 30 parts each of yellow corn, corn gluten, and millet; and as a mash a mixture of wheat bran 30 parts, shorts 25 parts, yellow corn meal 25 parts, and meat scraps 20 parts. Skim milk was given *ad libitum*. Green feed was daily provided by the use of

fresh, green, crushed clover. A deep litter of cut corn fodder was furnished in which the birds were compelled to work actively for their scratch feed. These animals grew at very rapid rates for 8 weeks, reaching weights varying from 332 to 417 gm. in that time. At the end of that time they all began to develop leg weakness with varying degrees of intensity. There were two factors contributing to leg weakness in the lot; first, they were overfed a highly concentrated diet and second, they did not eat enough of the roughage available and in consequence a dilution of the diet was not secured. Had the roughage been incorporated in adequate quantity with the grains and concentrates

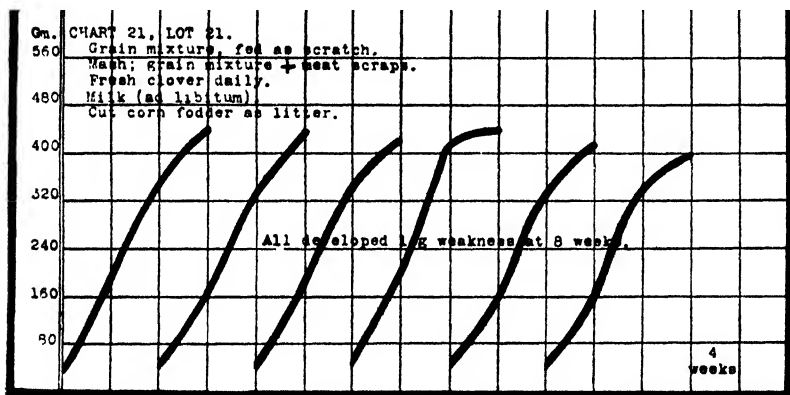


CHART 21. With all known nutrient factors present and with exercise and green feed furnished we may have leg weakness develop. The absent factor was an adequate consumption of roughage.

thereby compelling a lower consumption of absorbable nutrients probably no trouble would have resulted.

Again, as an illustration of the necessity of an intimate incorporation of the roughage, at least with synthetic diets to be used in the study of the nutrition of chickens, Charts 22 and 23 are added. In one instance we provided a cut oat straw litter and in addition mixed into the ration 10 per cent of cut oat straw. The straw was cut in lengths of approximately $\frac{1}{4}$ to $\frac{1}{2}$ inch. Leg weakness developed with three of the birds in 6 to 18 weeks and terminated their lives. The other 3 also developed this trouble, but in milder form, and grew at a slower rate of 15 to 16 weeks

when they were discarded. It is apparent that unless this class of animals will voluntarily eat the roughage in plentiful quantity, merely having it present and trusting to a haphazard consumption is to invite a high mortality. Further, it is altogether probable that the roughage should either be practically inert and lacking in taste, or should be one of an attractive palatability.

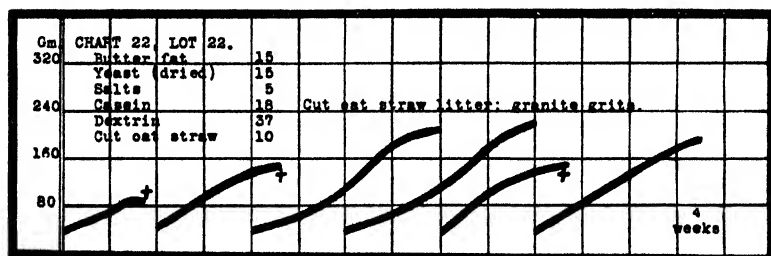


CHART 22. A failure to rear baby chicks when the roughage can be picked out and is not consumed. In this case cut oat straw served as the roughage.

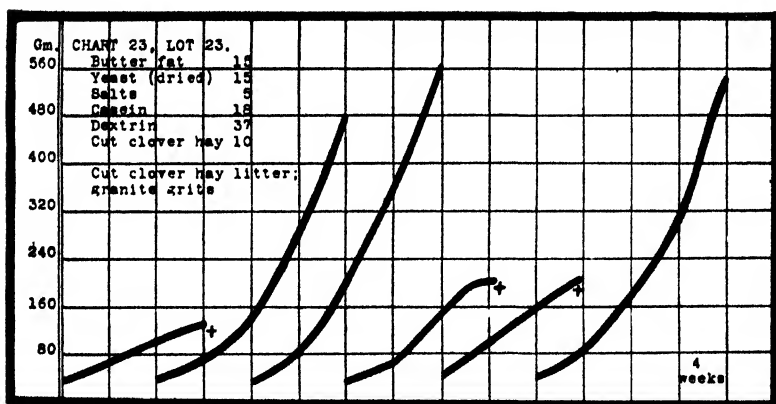


CHART 23. Another failure to rear baby chicks where the roughage is not intimately a part of the ration or so attractive in palatability as to invite consumption.

In Chart 23 are shown results secured with dry, cut clover hay used as a litter and also incorporated in the synthetic ration in the proportion of 10 per cent. Leg weakness developed in three of the birds of this lot and with such seriousness as to result in death at the end of 12 weeks. The other three birds made

slow initial growth and also developed mild symptoms of leg weakness. From this early attack of leg weakness they apparently recovered at the end of 12 weeks and showed a normal condition. The coarseness of the roughage used in these latter experiments allowed picking out which no doubt was the determining factor in both rations made with cut straw and cut clover. This would explain individual variations such as observed here, those birds getting on better when they did not separately consume the concentrated food material, but ate the entire mixture, including the roughage.

DISCUSSION.

Our results on the study of the use of synthetic diets for the rearing of baby chicks points toward the primary importance of an indigestible ballast in their ration. Why we should have such variations in the effectiveness of these materials used is impossible to state. Possibly agar failed because it may have been digested in the tract of this species, or it is possible that as a gel in the intestine it was less effective as an absorbent than charcoal, dirt, or paper; we did have some success with it at a level of 10 per cent. Fullers' earth is of a pasty character and was very inefficient as a ballast; because of its effectiveness as an absorbent it is possible that it prohibited the full reabsorption of certain essential nutrient factors, thereby hastening death. But speculation as to how these materials acted in the tract is unprofitable.

We questioned whether there might be a direct correlation between leg weakness and an abnormal permeability of the intestinal wall, believing that herein may be found the real explanation for the prevention of this trouble with an effective roughage, in that it acts as an absorbent and ready means for the elimination of toxic materials generated in the tract. With this end in view a number of precipitin reactions was made on the blood of chickens suffering from leg weakness. The precipitin tests were carried out according to the technique of Kolmer and were made for us by Dr. P. W. Boutwell of this laboratory.⁶ The solu-

⁶ Kolmer, J. A., *A practical text-book of infection, immunity and specific therapy*, Philadelphia and London, 1915.

tion of the protein against which it was thought that the animal might be sensitized was prepared as follows: 20 gm. of the ground feed (oats, corn, etc., as the case might be) were shaken up with 200 cc. of an 0.85 per cent NaCl solution and allowed to stand 1 to 2 hours. It was then filtered through a fluted filter and finally through a Berkfeld filter. This gave a perfectly clear solution which foamed on shaking and clouded on heating, after adding a drop of 25 per cent nitric acid. The chicken was bled from the neck into small dishes, care being taken to keep the blood under as sterile conditions as possible. The blood was allowed to stand for a few hours until a clear serum separated which could be drawn off into a sterile pipette. The tests were carried out as follows: to 2 cc. of the protein solution in test-tubes were added two drops of the serum to be tested. The tubes were then incubated and observed at short intervals. In no case was there a positive precipitin test obtained. After a longer incubation a cloudiness was usually observed in the tubes, but the same occurred in the control when the serum was added to a salt solution alone. The addition of large amounts of the serum also caused a cloudiness in both the protein solutions and the control. As stated, all the results were negative. To check the method a white cockerel was sensitized against milk proteins by injecting 5 cc. of milk into the large vein under the right wing. 4 days later 10 cc. of milk were injected into the vein under the left wing. 6 days later 10 cc. of milk were injected intraperitoneally. After a further period of 10 days the cockerel was bled and positive precipitin tests were obtained when the serum was added to milk diluted 1 to 50 and 1 to 500. The fact that the precipitin tests were negative does not exclude the probability that leg weakness is due to an undue absorption of toxic substances and that the real function of roughage is to help in their ready elimination.

The fact that fowls suffering from leg weakness have an anemic appearance led us to make a number of hemoglobin examinations in the case of leg weakness as well as of normal specimens. The determinations were made using the Fleichl-Miescher hemometer. The chickens were bled from the wing vein. Determinations on six separate individuals suffering from leg weakness at various stages of severity showed a hemoglobin content varying from

7.45 per cent to 11.2 per cent. The amount found in normal birds averages 7.49 per cent. These data would indicate that in this disease there was not a subnormal hemoglobin content in the blood.

SUMMARY.

1. Our work points to the conclusion, which is in confirmation of the work of Osborne and Mendel, that the disease known among poultrymen as leg weakness is caused by the lack of a suitable roughage in the ration.

2. Among the roughages tried with our synthetic ration were paper, charcoal, dirt, agar, and fullers' earth. Paper in a concentration of 10 per cent of the ration was the most effective roughage used; agar was much less effective and fullers' earth almost worse than nothing.

3. The use of green cabbage, green clover, or of orange juice did not, in the absence of a suitable roughage, prevent the progress of this disease. Consequently we do not believe that leg weakness is a scurvy of chickens.

4. Provision for plenty of exercise or green feed will not prevent leg weakness if the bird at the same time is overfed a concentrated ration.

5. We obtained no evidence in cases of leg weakness that animals were sensitized to the proteins of their food. The blood did not show the precipitin reaction for the food proteins used. This would indicate that the food proteins as such were not traversing the intestinal wall. This negative evidence does not preclude the possibility of undue absorption into the blood stream of intestinal waste products in cases of leg weakness. The hemoglobin content of the blood of leg-weak chickens was not different from that of normal birds.

6. Our success with paper and the synthetic diet will make possible a study of the quantitative relations of the factors of nutrition in the growth of chickens.

EXPLANATION OF PLATES.

PLATE 1.

FIG. 1. A typical case of leg weakness. This result was produced by our synthetic diet containing no roughage. Photographed when 90 days old.

FIG. 2. Reared on a synthetic diet containing 10 per cent of dirt. Weighed 1,092 gm. when photographed at 14 weeks of age. Although not fully feathered this bird appeared normal.

PLATE 2.

FIG. 3. Reared on a synthetic ration containing 20 per cent of charcoal. Weighed 994 gm. when photographed at 14 weeks of age. Although not fully feathered this bird appeared normal.

FIG. 4. Reared on a synthetic diet containing 10 per cent of paper reground with the ration. Weighed 710 gm. at 16 weeks and apparently was in perfect health.



FIG. 1.



FIG. 2.

(Hart, Halpin, and Steenbock Synthetic diets for baby chicks)



FIG. 3.



FIG. 4.

(Hart, Halpin, and Steenbock: Synthetic diets for baby chicks.)

AMINO-ACIDS IN NUTRITION.*

I. STUDIES ON PROLINE: IS PROLINE A GROWTH-LIMITING FACTOR IN ARACHIN (GLOBULIN FROM THE PEANUT)?

BY BARNETT SURE.

(From the Laboratory of Agricultural Chemistry, University of Wisconsin, Madison.)

(Received for publication, April 22, 1920.)

Perhaps there is no problem in the realm of physiological chemistry that is more significant than the question of the synthetic power of the animal organism for the individual amino-acids of the proteins. That the animal body is able to synthesize glycine is a well established fact (1). That it requires tryptophane, the indole nucleus of the protein chain, and is unable to make it itself has been established by Willock and Hopkins (2), Abderhalden (3), Osborne and Mendel (4), and Wheeler (5). That the same is true of cystine is evident from the fact that Osborne and Mendel (6) procure such remarkable increases in weight of their animals when small amounts of isolated cystine are added to low planes of intake of casein, which has a low cystine content. Similar results were reported recently by Johns and Finks (7) in the case of phaseolin, the globulin and the main protein from navy bean.

In connection with lysine, Hart, Nelson, and Pitz (8), contrary to the findings of Osborne and Mendel (9), recently produced evidence that the mammary gland is unable to synthesize this complex.

With regard to tyrosine, we have conflicting evidence. Abderhalden (3) claims that this complex is essential for growth, while Totani (10) believes that the animal cell has the power of synthesizing the hydroxy-phenyl nucleus of the protein molecule.

* This article forms part of a thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of Wisconsin.

Hopkins (11) has recently reported that arginine and histidine can replace each other when equimolecular amounts of either are added to the ration; also that with a diet made up of histidine, cystine, tyrosine, tryptophane, and lysine, that is a diet containing five out of the eighteen amino-acids of a protein, there occurs a remarkably slow loss of weight and long maintenance with apparent health. However, with a diet made up of leucine, valine, alanine, glycine, and glutamic acid, loss of weight is rapid and the animals soon succumb. Hopkins' work shows the relative indispensability of the ring compounds and the lesser importance of the monoamino-acids in proteins for nutrition.

EXPERIMENTAL.

As noted in this short review of the literature, no attempt has yet been made to determine the synthetic capacity of the animal cell for the pyrrole nucleus as found in proline. It was this problem which was submitted to experimental inquiry and the results thus far secured are presented in the following protocols and discussions.

As proline is present in considerable amounts in most proteins, it was not found possible to feed a protein entirely deficient in it, with the aim of ultimately making proline additions and noting the resultant improvement in the growth of the animals. Furthermore, as proline is not destroyed by hydrolysis or quantitatively precipitable, it was impossible to feed cleaved proteins from which all proline had been removed. Recourse therefore was had to the use of such proteins as have been reported low in proline, with the hope that their proline content might be sufficiently low to bring out possible limitations of the synthetic capacity of the animal. Three proteins which qualified with respect to a low proline content are edestin, lactalbumin, and arachin. In edestin, the globulin from hemp seed, about 1.7 per cent of the nitrogen is in the form of non-basic non-amino nitrogen (12), which is equivalent to 2.6 per cent of the protein as proline. In lactalbumin, the heat-coagulable protein from milk, Osborne and associates found 1.8 per cent of the nitrogen in the non-basic non-amino form (12), which presumably represents proline and oxyproline nitrogen. In the same protein

Crowther and Raistrick report 2.0 per cent of the nitrogen in the same fraction, using the same method of analysis (13). In the following experiments edestin was not used, as the large quantities necessary for the experiments are prepared only with difficulty. Lactalbumin also was not used as a primary constituent of the rations, because it was later found, as brought out in the following paper (14), that in this protein cystine and tyrosine are the growth-limiting amino-acids. Arachin alone, as isolated by Johns and Jones (15), was finally chosen as it is readily prepared and is the lowest in proline of any protein yet reported. Their analysis of this protein follows (16):

	<i>per cent</i>
Glycine.....	0 00
Alanine.....	4 11
Valine.....	1.13
Leucine.....	3 88
<i>Proline</i>	<i>1.37</i>
Phenylalanine.....	2.60
Aspartic acid	5.25
Glutamic acid.....	16 69
Serine.....	—
Oxyproline.....	—
Tyrosine.....	5.50
Cystine	0.85
Arginine.....	13.51
Histidine.	1.88
Lysine	4.98
Tryptophane.....	Present.
Ammonia.....	2 03

63 78

It will be noted from the above table that arachin is a complete protein in so far as it contains all the amino-acids, with the exception of glycine and possibly serine and oxyproline, thus far isolated as final hydrolysis products of proteins by chemical methods. It is rather low in cystine and in proline. It is also rather low in histidine, containing only 1.88 per cent, but remarkably high in arginine, 13.51 per cent, and, if Hopkins' idea of the transformation of arginine and histidine into each other by the animal cell is correct, then there ought to be more than sufficient arginine to take care of the possible deficiency of histidine. Tryp-

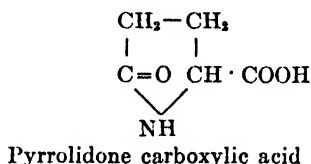
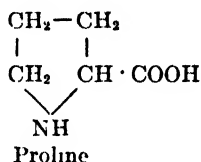
tophane evidently was not determined quantitatively and the data are only qualitative. In order to eliminate cystine and tryptophane as possible limiting factors before a response to proline addition could be expected, they were added to the extent of 1.0 and 0.5 per cent of the protein, respectively. Since casein is reported by Hopkins and Cole (17) to contain only 1.5 per cent tryptophane, and, furthermore, since arachin is shown to contain this amino-acid, 0.5 per cent additions of tryptophane were considered to be sufficient to eliminate that constituent as a possible limiting factor.

All the data that were collected were obtained using rats as the experimental animals. The rats were confined in wire cages in small groups and kept under sanitary conditions, being at all times abundantly provided with the rations fed and with distilled water. Among the ingredients in the ration, the water-soluble vitaminé was introduced in the form of an alcoholic extract of wheat embryo—previously extracted with ether—in such amounts that each 100 gm. of ration carried the extract from 15 gm. of wheat germ. The extract was evaporated on the dextrin before being introduced in the ration. The salt mixture was one previously used in this laboratory (18).

The proline used in this feeding work was first prepared by the Fischer ester method (19). Proline has no amino group and consequently should contain no amino nitrogen; however, both the racemic and optically active proline contained 10 to 12 per cent amino nitrogen. This foreign amino nitrogen could come only from alanine, leucine, and valine, or the leucine fraction; and, therefore, the latter was fed as a control. During the process of distillation of the esters it was not always possible to maintain as low a pressure as 0.5 mm. and at times 2 to 3 mm. pressures were employed and, therefore, the temperature often had to be raised slightly, possibly carrying over traces of the next fraction of esters. Such a condition may very well have influenced, at least partly, the solubility of some amino nitrogen in the presence of proline in absolute alcohol. Later, proline was prepared by the method of Fischer and Boehner (20) not involving esterification. By slightly modifying the technique of these authors by introducing phosphotungstic acid to precipitate the bases, proline was obtained which contained only 5 per cent

amino nitrogen. The fact that Van Slyke (21) introduced a method for determining proline by the difference between the total and amino nitrogen of the alcoholic extracts of the leucine fraction in itself suggests that it is not always possible to procure proline absolutely free from some amino nitrogen.

Supplementary to the experiments where proline was added to the ration some attempts were made to use pyrrolidone carboxylic acid instead. The great similarity in structure of these two compounds

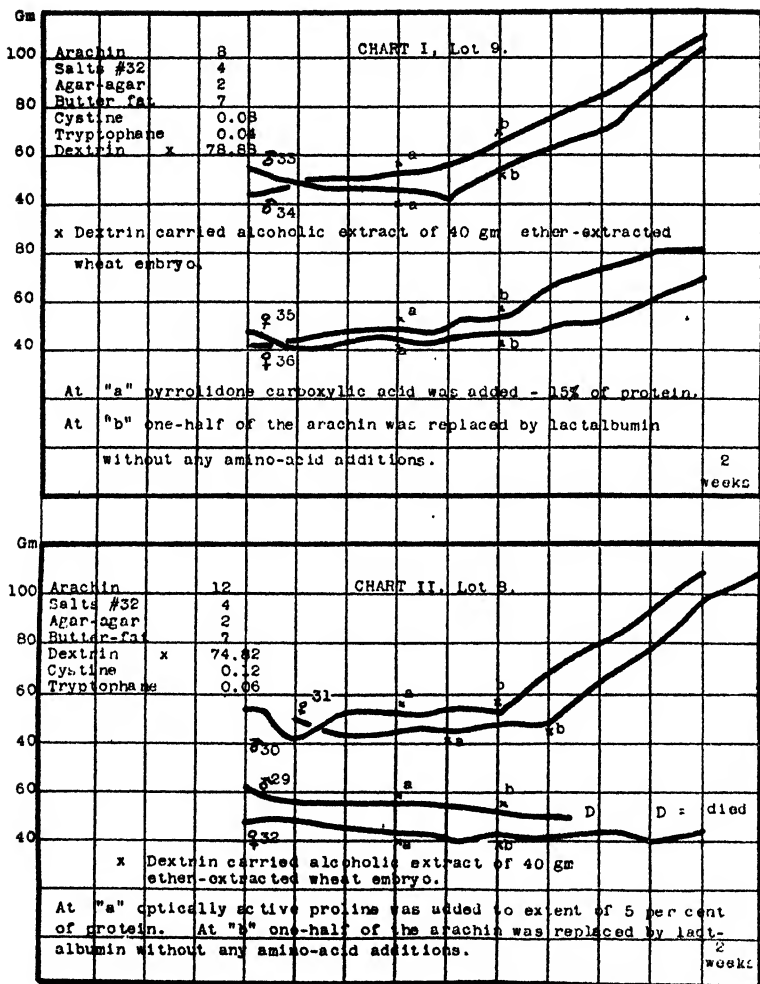


and the ease with which pyrrolidone carboxylic acid is formed from glutamic acid made a determination of the possible functions of this derivative very interesting. It was prepared in quantity by Foreman's method (22) and was used in a few experiments.

With the aim of ascertaining the conditions under which supplementary additions of proline might be expected to produce the most decisive results, it was necessary to determine first the increments of growth possible on various planes of arachin intake. As no data on the biological efficiency of arachin were available, it was necessary to establish these fundamental relations which are brought out in the following protocols.

Chart I, Lot 9.—Arachin obviously gives no indication of containing a mixture of amino-acids of unusual value for satisfying the requirements of the growing organism, otherwise an intake at a level of 8 per cent of the ration—especially when supplemented with cystine and tryptophane—should have made possible more than maintenance in these young rats. In this lot in a preliminary test at "a" a 0.12 per cent addition of pyrrolidone carboxylic acid was made with negative results, but when at "b" 4 parts of arachin were replaced by lactalbumin—also in itself a poor protein—some growth was made possible.

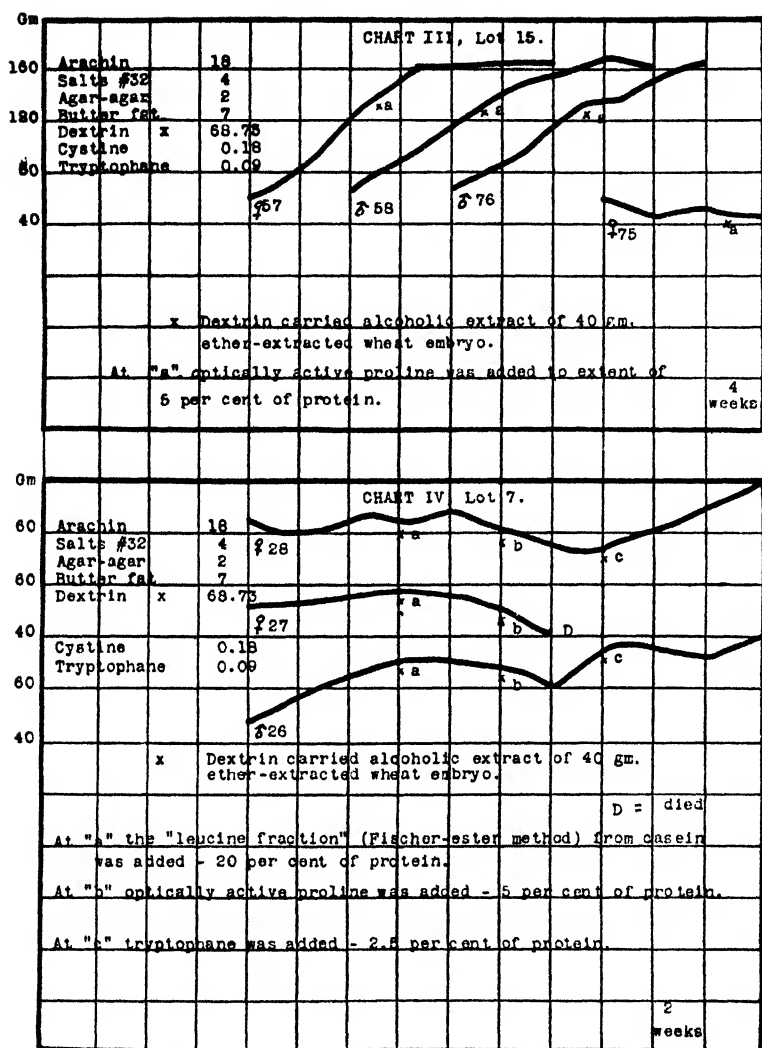
Chart II, Lot 8.—12 per cent of arachin supplemented with cystine and tryptophane gave no indication of possessing greater value for inducing growth in rats on an otherwise satisfactory ration than 8 per cent of arachin (Chart I, Lot 9). When at "a" there was added in addition to the cystine and tryptophane l-proline equivalent by weight to 5 per

CHARTS I AND II.¹

cent of the arachin no improvement resulted, but when later one-half of the arachin was replaced by lactalbumin, as in Chart I, growth was made possible.

Chart III, Lot 15.—Even when fed at an 18 per cent level and when supplemented with cystine and tryptophane, arachin proved to be a poor protein. A small amount of growth resulted at this intake but it was not

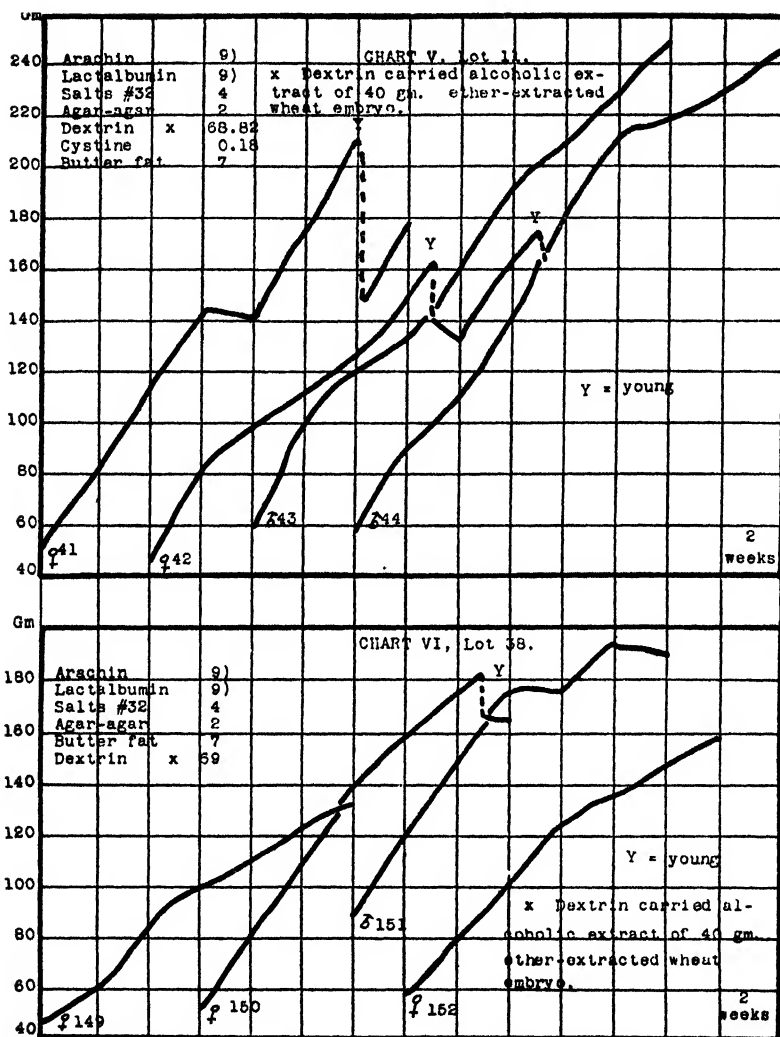
¹ In all charts, for "40 gm. ether-extracted wheat embryo" read "15 gm. ether-extracted wheat embryo."



CHARTS III AND IV.

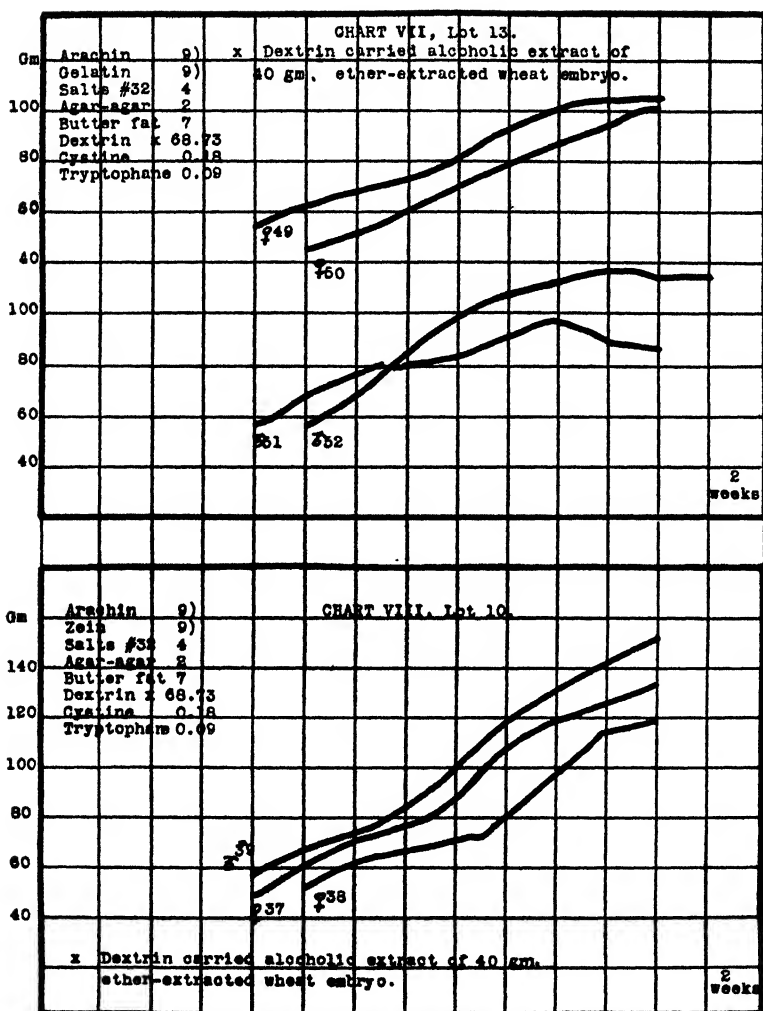
maintained even when at "a" l-proline to the extent of 0.9 per cent of the ration or 5 per cent of the protein was added.

Chart IV, Lot 7.—Here the feeding of the basal ration containing 18 per cent arachin as in Chart III, Lot 15, was duplicated with, however, less resultant growth and this in spite of the fact that adequate consumption



CHARTS V AND VI.

for growth was obtained. At "a" the ration was supplemented with a leucine fraction (Fischer ester distillation) from casein, and at "b" by l-proline in addition. Though the proline was added in an amount equivalent to 5 per cent of the arachin, and at "c" an additional amount of tryptophane was introduced, so that in all 2.5 per cent of the weight of protein in tryptophane had been added, no growth resulted. Alanine,



CHARTS VII AND VIII.

leucine, valine, cystine, tryptophane, and proline are, therefore, eliminated as primary factors in the limitation of growth of the animal when arachin is the sole source of protein.

Chart V, Lot 11.—Of the probable supplementary value of lactalbumin and arachin some evidence has already been presented (Charts I and II). Here we have indications that in the presence of cystine the supplementary effect is of a high order of efficiency.

Chart VI, Lot 38.—In the absence of additional cystine very good supplementary effect was produced. On the whole, the performance of the animals was not so good here as in Chart V, Lot 11, but this may be considered eliminated when consideration is given to the fact that this lot contained three females instead of two.

Chart VII, Lot 13.—Subjecting the failure of l-proline to enhance efficiently the value of arachin for production of growth in the rat to further analysis, it is seen that gelatin, though it is very rich in proline—7 per cent—likewise is of little or no value. Conditions were, however, somewhat different from those obtained with the rats on the arachin-cystine-tryptophane diets, as these animals were very irritable, became emaciated, and lost some of their hair. In spite of this, somewhat more growth was obtained, yet the increment was not sufficient to be of decisive value.

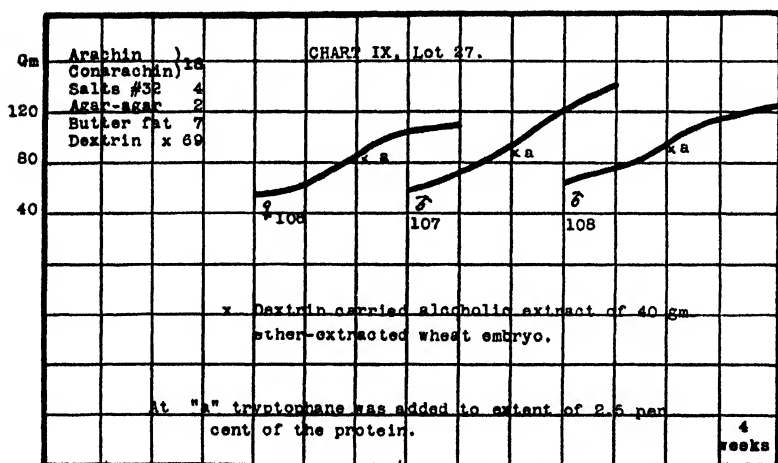


CHART IX.

Chart VIII, Lot 10.—Zein, another protein high in its proline content—9 per cent—when used as a supplement to arachin brought the animals into the same state as gelatin, with this exception that after 8 weeks there ensued recovery from their poor nutritive condition; yet little growth resulted. It was surmised that failure of growth might have been due to the indigestibility of the zein, but an attempt to feed hydrolyzed zein led to failure as the animals refused the ration.

Chart IX, Lot 27.—While not strictly germane to the subject under consideration, yet it was of interest to determine the biological value of the mixture of globulins, arachin and conarachin, as they are extracted from the peanut by salt solutions. As seen on the chart, no better results were obtained with these than with arachin alone. Tryptophane added at "a" to the extent of 2.5 per cent of the protein proved not to be the limiting factor.

DISCUSSION.

In the data presented it is shown that arachin is biologically a poor protein. Other proteins showing a similar distribution of amino-acids have been found to be good proteins. It is, however, true that the available analysis of arachin, as with other proteins, leaves much to be desired, because only a fraction, 63 per cent, of the amino-acids has been isolated (16). Assuming that arachin was either a good or poor protein in spite of or by virtue of its low proline content, 1.37 per cent, proline additions were made. When these additions were made, even in the presence of additional cystine and tryptophane, which have already been found to be growth-limiting factors with other proteins, negative results were obtained. Furthermore, the fact that neither gelatin nor zein, which are both high in proline, supplement this globulin of the peanut gives evidence that proline is not the growth-limiting factor in arachin.

With lactalbumin efficient supplementation was secured but unfortunately this does not give unequivocal evidence as to the character of the deficiency of arachin. It cannot have been tryptophane which is contained in lactalbumin, because in one experiment this amino-acid was added to the extent of 2.5 per cent of the arachin (Chart IV, Lot 7; Chart IX, Lot 27) and no response was secured. It also cannot have been cystine because cystine added equivalent to 1 per cent of the arachin, in the presence of tryptophane, was also ineffective and furthermore lactalbumin itself is deficient in this amino-acid (14).

It is also true that arachin is rather low in histidine, 1.88 per cent, but on the whole, judging from its chemical composition, and also making additional allowance for the 37 per cent of the amino-acids that were lost in manipulation, this protein ought to be fairly good for growth. Actually, however, even with additions of cystine, tryptophane, proline, alanine, leucine, and valine, it serves for little better than maintenance.

Although according to present data arachin contains in quantity all the amino-acids believed to be necessary for the construction of mammalian body tissue, it was in these experiments found inadequate for maintaining growth in the rat. For this apparent inconsistency between chemical and biological tests

there is no explanation at present. It is quite possible, however, that this anomalous condition may be clarified if we accept that constitutional differences as well as qualitative and quantitative distribution of amino-acids may determine the biological value of a protein. It is quite possible that the chemical structure of the protein may be such that after digestion certain of the simple peptides containing some amino-acid essential for the construction of body tissue escape further cleavage and present themselves in a form unacceptable for assimilation into body tissue. In this connection it is to be remembered that, while amino-acids have been isolated from blood and while an increase in non-protein, non-urica nitrogen and an increase in free amino nitrogen has been observed during digestion, it is still not evident as to the form in which the nitrogen is assimilated by the tissues from the blood stream. It may be absorbed as peptides or as amino-acids or as both. In the latter case the quantitative relations between these processes would determine the issue. It is not intended to enter into a discussion of this phase of the subject further than to point out how imperfect hydrolysis may modify assimilatory processes. For differences in the cleavage of peptides by enzymes the work of Abderhalden done *in vitro* gives abundant evidence.

Fischer and Abderhalden (23) demonstrated that *in vitro* trypsin is able to hydrolyze certain polypeptides while it will not split others due to differences in arrangement. To give the simplest example, alanyl-glycine, $\text{CH}_3.\text{CHN}_2.\text{CO}.\text{NH}.\text{CH}_2.\text{COOH}$, is hydrolyzed while its isomer, glycyl-alanine, $\text{NH}_2.\text{CH}_2.\text{CONH}.\text{CH}.\text{(CH}_3\text{)COOH}$, is not. Numerous more complicated instances are cited but it is sufficient to say that configuration is an important factor determining whether certain polypeptides will be and whether others will not be hydrolyzed by enzymes. That a similar situation may exist in the digestive tract of the animal organism is suggested; and, until further experimental data based on specific amino-acid additions are obtained which may improve the poor quality of arachin, it is tentatively proposed that the deficient character of arachin is to be attributed to its stereochemical rather than to its chemical composition.

It remains, however, to establish that proteins differ in the arrangement of their component amino-acid constituents to the extent that incomplete hydrolysis in a given time would obtain with one and not with the other. As far as known to the author differences in the digestibility or rate of digestion of peptides isolated from proteins has not been demonstrated.

Although arachin is deficient as a food protein, it is interesting to note that Daniels and Loughlin (24) have recently shown that the total proteins of the peanut are satisfactory for growth. Peanuts, then, must have other proteins that supplement arachin.

SUMMARY.

1. Arachin is biologically a poor protein in spite of the fact that chemical analysis indicates absence of no necessary amino-acid.

2. *Proline is not a growth-limiting factor in arachin.*

3. Neither gelatin nor zein, which are high in proline, supplements arachin. This fact is additional evidence that proline is not the nucleus responsible for the poor biological value of that globulin of the peanut.

4. Tryptophane and cystine when added to the extent of 2.5 and 1.0 per cent of the total protein respectively did not improve the deficient character of arachin.

5. The leucine fraction, composed of a mixture of alanine, leucine, and valine, did not improve the nutritive value of arachin.

6. Lactalbumin, in itself a deficient protein biologically, supplements arachin, but to a much greater extent in the presence of cystine.

7. Arachin is not supplemented by its sister globulin, conarachin.

The author wishes to express his appreciation to Professor E. B. Hart and Professor H. Steenbock for many valuable suggestions and criticisms in connection with this work.

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AMINO-ACIDS IN NUTRITION.*

II. THE NUTRITIVE VALUE OF LACTALBUMIN: CYSTINE AND TYROSINE AS GROWTH-LIMITING FACTORS IN THAT PROTEIN.

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(Received for publication, April 22, 1920.)

Since 1911, when Osborne and Mendel published their first work on "Feeding experiments with isolated food substances," there has been made accessible to investigation the problem of the biological evaluation of proteins as correlated with their chemical analyses. It is true that for a time the advance made in the solution of this problem was obscured by the lack of appreciation of the necessity of the presence of the water-soluble and fat-soluble vitamins, but this was soon rectified as information in connection with these vitamins was accumulated by Hopkins (1), McCollum and Davis (2), and by Osborne and Mendel themselves (3).[¶] However, with the incorporation of the water-soluble vitamin in the diet in the form of the extracts in which it is known new complications were introduced, inasmuch as this also meant the introduction of a small amount of nitrogen in unknown forms. Some of the earlier work in this field was, therefore, open to much criticism, as unquestionably in many instances the amino-acid deficiency of a protein was covered by the amino-acid nitrogen contained in the vitamin preparations used in excessive amounts. Even with the present technique of ration-compounding this difficulty has not been entirely circumvented, but it has at least been minimized by the use of vitamin preparations low in nitrogen and minimum in amount (4).

* This article forms part of a thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of Wisconsin.

In the early work of Osborne and Mendel, lactalbumin no more than edestin or other globulins was able to support growth, but here the fat-soluble vitamine was not incorporated in the diet and little else was to be expected. In 1916, in a series of experiments designed to test the comparative values of casein, lactalbumin, and edestin, these same workers found that lactalbumin was a protein of unusual value; in fact, 50 per cent more casein and 90 per cent more edestin than lactalbumin were required to produce the same increment in growth (5). Later, however, in another series of experiments they found lactalbumin, as well as cotton-seed globulin, cotton-seed protein, or squash seed globulin, invariably unable to support growth (6). These conflicting data were harmonized when it was appreciated by them that where failure had supervened yeast had been used as the source of the water-soluble vitamine, while where success had been obtained their so called protein-free milk had been used instead. Evidently, then, here occurred a concrete instance of supplementation of an "incomplete" protein by the nitrogen of a water-soluble vitamine preparation from milk. Possibly the statement of McCollum, Simmonds, and Parsons (7) that lactalbumin is a poor protein can also be harmonized on these general premises. Another suggestion has been made by Emmett and Luros (8), in which they state that lactalbumin is a complete protein and that their success was due to a vitamine, with a possible detoxifying effect, carried by the lactose and not introduced by other investigators. It scarcely appears necessary, however, in the light of present information to advance such hypotheses, in addition to those already advanced, which are based on the supplementary value of the nitrogen carried by the vitamine preparations. It becomes increasingly desirable, however, to establish definitely the specific amino-acids which limit the nutritive value of lactalbumin.

EXPERIMENTAL.

All the experiments were carried out on young rats according to the technique which has become a standard in this laboratory in the course of the last few years. As basal constituents there were used dextrinized corn-starch, agar-agar for roughage, Salt No. 32 for mineral constituents, filtered butter fat for fat-soluble

vitamine, and an alcoholic extract of ether-extracted wheat embryo for water-soluble vitamine. Before the experimental details were fully organized one ration containing yeast as the source of water-soluble vitamine was started, but this was later changed as the wheat embryo preparation was found to introduce only one-third as much nitrogen as the yeast. Although comparative supplementary values could not be forecast, it appeared to be desirable on general premises to introduce the minimum of nitrogen that might be of possible supplementary value.

As the individual proteins of milk may not be as definite entities as is ordinarily assumed, it appears desirable to describe the method of preparation of the lactalbumin used in some detail. The small amount of so called albumin in milk as obtained by heat coagulation after the removal of the casein made it almost impossible to consider milk as a source for its preparation. Instead there was used the whey produced in the manufacture of cottage cheese by the lactic acid fermentation process. 1,000 to 2,000 pound lots of this whey were run through a centrifugal whey separator to remove small particles of casein held in suspension and then heated by steam to about 85°C. for 1 hour. Care was taken to avoid violent agitation, as otherwise the coagulated albumin particles do not coalesce and their collection is made difficult. After settling for 1 hour the supernatant liquors were run off through a large wire strainer covered with three layers of cheese-cloth. The albumin left in the vat was united with that caught by the strainer and after standing for 24 hours was decanted free from excess liquors and worked up repeatedly by hand with 40 liters of chloroformed tap water for a week. This was done to wash out soluble forms of nitrogen of possible supplementary nutritive value. The supernatant liquor was finally allowed to drain off through the strainer, and the albumin dried in a steam oven at a temperature not exceeding 75°C. Final purification with hot 95 per cent alcohol left a product faintly tinged with yellow. On analysis it was found to contain from 0.5 to 0.7 per cent ash, 0.06 per cent phosphorus, and 14.3 to 14.7 per cent nitrogen.

Chart I, Lot 4.—Lactalbumin fed at an 18 per cent level in a low caloric ration and when supplemented with cystine to the extent of 1 per cent of the weight of the protein met the requirements for growth in the rat.

Chart II, Lot 5.—By comparison with Chart I, Lot 4, it is seen that when the cystine is omitted from the ration the growth of the animals is far from being satisfactory. Of the four animals fed on this ration one was able to grow at a rate which may be considered normal, but, on the other hand, three failed to continue their growth. This is to be taken as indicating a deficiency of the ration, for while the one animal was able to grow, that ability no doubt was resident in either a larger consumption of the ration, or else in a greater efficiency in conserving available sulfur complexes in the body.

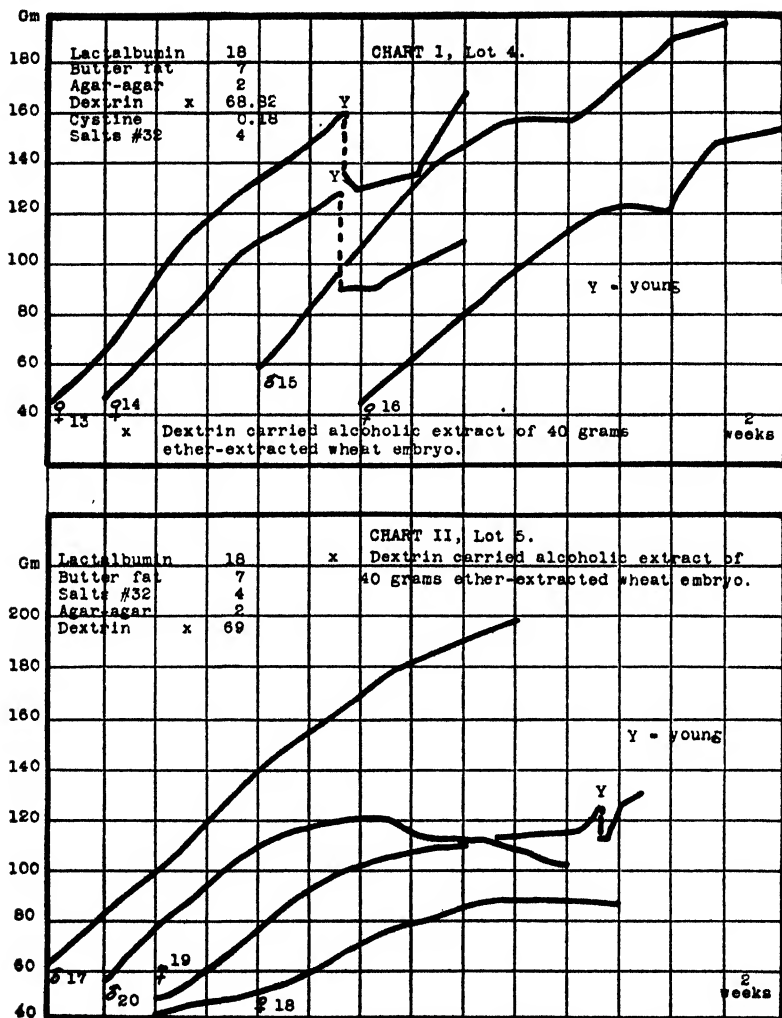
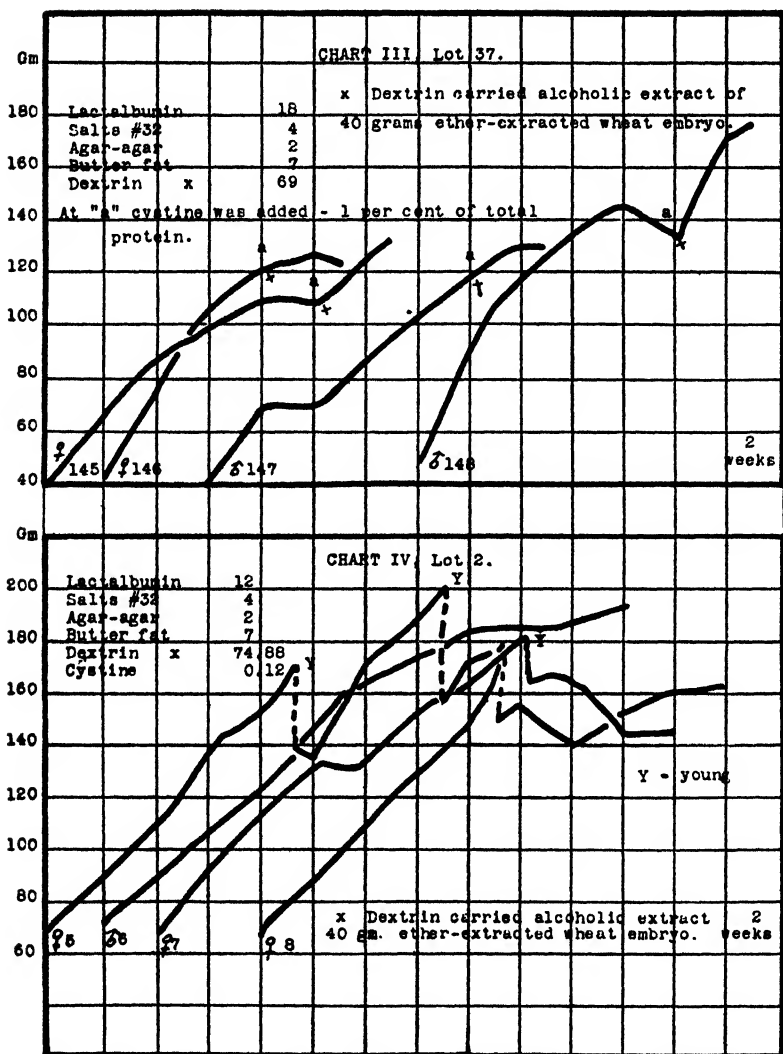
CHARTS I AND II.¹

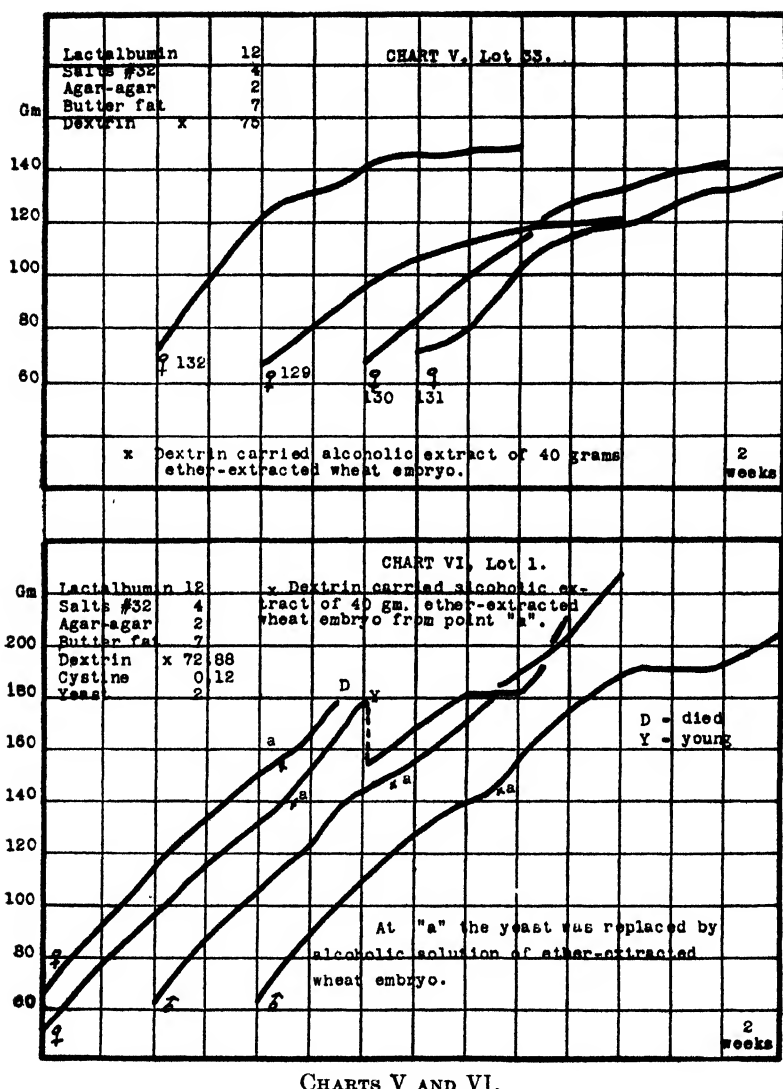
Chart III, Lot 37.—A duplication of the experiment of Chart II, Lot 5, resulted in good growth of the four animals for a considerable period, but ultimately failure ensued in two animals out of the four in the time that the trial was continued. When at this point the ration was fortified with cystine there resulted prompt recovery. This emphasizes the point indi-

¹ In all charts, for "40 gm. ether-extracted wheat embryo" read "15 gm. ether-extracted wheat embryo."



CHARTS III AND IV.

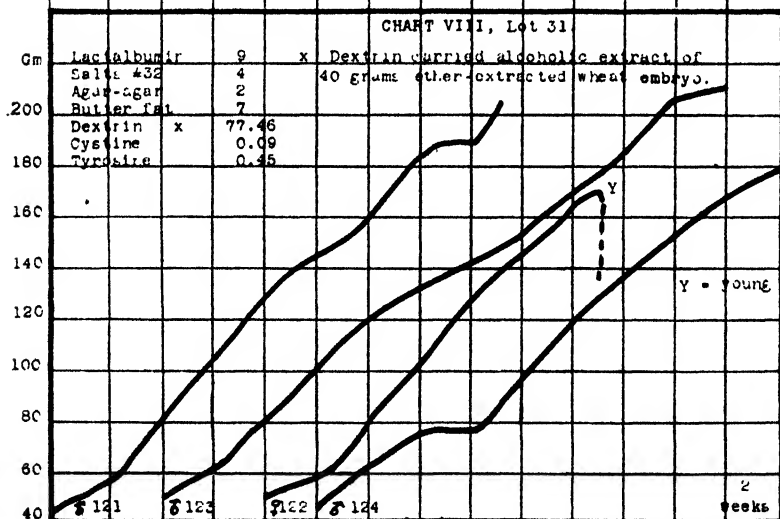
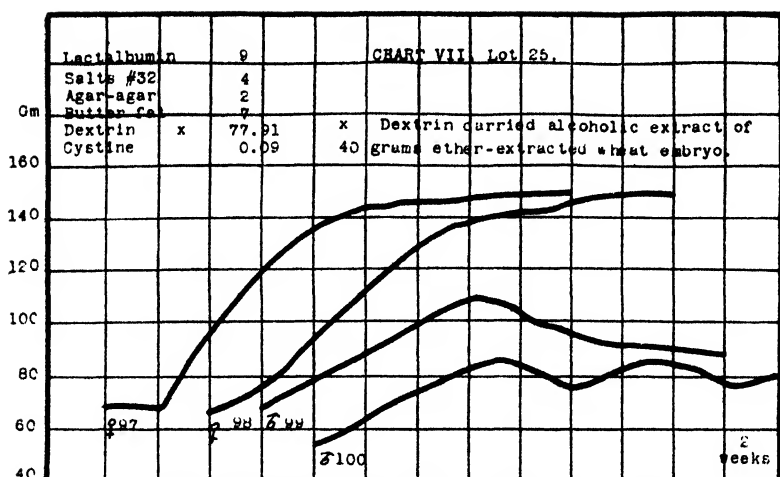
cated in the previous chart that cystine is a limiting factor in the biological efficiency of lactalbumin. The fact that the two animals did not respond to the addition of cystine does not detract from the value of the data, as this may well have been due to irreparable injury directly or indirectly caused by the amino-acid deficiency.



CHARTS V AND VI.

Chart IV, Lot 2.—Lactalbumin at a 12 per cent level supplemented with 1 per cent cystine supported a fair amount of growth.

Chart V, Lot 33.—When not supplemented with cystine at a 12 per cent lactalbumin level the growth performance was considerably inferior (*Chart IV, Lot 2*).



CHARTS VII AND VIII.

Chart VI, Lot 1.—When yeast was used as the source of the water-soluble vitamins, lactalbumin on a 12 per cent level supplemented with 1 per cent of cystine allowed the rats to make excellent growth. At "a" the yeast was replaced by an alcoholic extract of ether-extracted wheat embryo, such as was used in the other rations, and growth continued for the

duration of the trial. While in itself not conclusive, as the supplementary value of the yeast alone was not determined, yet Osborne and Mendel's findings that lactalbumin was a poor protein when yeast was used as a source of the water-soluble vitamine strongly suggest that the addition of cystine was here responsible for the excellent growth. The continuation of growth when the change in water-soluble vitamine from yeast to an alcoholic extract of wheat embryo was made bears out this suggestion.

Chart VII, Lot 25.—When supplemented with 1 per cent of cystine no such increment in growth is obtained with the lactalbumin fed at a 9 per cent level as when fed at a 18 or even 12 per cent level. At this low level of protein intake evidently other amino-acids are reduced in amount below the level where they can still allow growth to take place after the primary deficiency of cystine has been removed.

Chart VIII, Lot 31.—The amino-acid responsible for failure of growth in Chart VII, Lot 25, appears to be tyrosine. Growth was regular and long continued when the lactalbumin fed at a 9 per cent level was supplemented with tyrosine as well as cystine. From this it appears that when an alcoholic extract of wheat embryo is used as the source of the water-soluble vitamine tyrosine is the second growth-limiting factor in lactalbumin.

DISCUSSION.

It appears demonstrated that lactalbumin, if we accept as lactalbumin the proteins in milk removable by heat coagulation after the casein has been removed, is biologically an incomplete protein. This was brought out in feeding trials even when nitrogen in unknown forms had been introduced with the water-soluble vitamine in the ration, so that it constituted 2 per cent of the total protein nitrogen. Under the experimental conditions cystine proved to be an efficient supplement to the lactalbumin when the protein was fed at an 18 and at a 12 per cent level; yet lactalbumin is not unusually low in cystine, as it has been reported to have 1.30 per cent of its total nitrogen in the form of cystine or 1.74 per cent molecular cystine (9), which is about the average percentage of cystine in other proteins (10). Although arachin contains only about one-half as much cystine (0.88 per cent cystine nitrogen) as lactalbumin, no response to cystine additions was obtained in the case of arachin, even in the presence of tryptophane (11). This fact the author believes is further evidence to substantiate the theory set forth in a previous communication (11) that the efficiency of a protein may largely depend on its constitution as well as composition in amino-acids, and that

chemical analysis of amino-acid content may at times be inadequate to explain the nutritive failure or success obtained with certain proteins widely distributed in nature. It is quite possible that cystine is so oriented in the complex polypeptide chain of lactalbumin that when it is hydrolyzed by the enzymes in the digestive tract it is split into simpler peptides of such form that a great part of them escape further cleavage, and are, therefore, deaminized and converted to urea. Of course, it still leaves open the possibility that the animal organism requires more cystine than that actually contained in lactalbumin when that protein is fed at as high a plane of intake as 18 per cent of the total food.

Osborne and Mendel found lactalbumin to be a highly efficient protein when fed with protein-free milk, and the experimental data here presented show that cystine renders that protein of excellent nutritive value, when employing a synthetic salt mixture, and an alcoholic extract of wheat embryo for water-soluble vitaminine, when without cystine it is of little value. The author is consequently of the opinion that protein-free milk must either carry cystine as part of its nitrogen of unknown source, or other forms of organically bound sulfur which the animal organism can readily transform into cystine. An analysis of protein-free milk showed a sulfur content of 0.2 per cent, of which the greater part was in organic combination.

While growth was induced by the addition of cystine to lactalbumin when fed at 12 and 18 per cent levels, such was not the case when the protein was reduced to a 9 per cent level. This brings out the fact that, while cystine is the primary growth-limiting factor in lactalbumin, other amino-acids may also limit its usefulness when the intake is sufficiently reduced. With the protein under consideration this proved to be tyrosine, as complete success was obtained when the lactalbumin was fortified with 5 per cent of its weight of tyrosine.

Prior to this work the experimental evidence does not give definite information with regard to the indispensability of tyrosine for growth. The first notable experiment on this subject was conducted by Abderhalden (12) on a dog. A preparation of the digestion products of casein, freed from tyrosine as completely as possible, was given to the animal. The dog lost 750 gm. in 9 days and there was a further loss of weight in

the 4 following days, though the loss of weight in the last few days may have been partly due to an insufficient intake of food. The loss of weight, however, was regained almost entirely when tyrosine was added to the previously consumed dietary. Abderhalden, therefore, came to the conclusion that tyrosine is an essential amino-acid for nutrition.

Recently Totani (13) continued the work on tyrosine with a view to the possible replacement of that amino-acid by its corresponding ketonic acid. Since Abderhalden fed his protein freed from tyrosine by crystallization only, Totani made a much more painstaking and laborious attempt towards removing all traces of tyrosine from a casein-hydrolysis mixture. He found that after repeated crystallizations the material still gave a positive Millon's test. Mercuric sulfate and phosphotungstic acid were then used to precipitate out any residual amounts of tyrosine. He then found that the most efficient method of exhausting casein of its tyrosine content was to use a combined tryptic and acid hydrolysis. With all his most elaborate methods his final preparation of hydrolyzed protein was found to contain by colorimetric measurements 0.3 per cent tyrosine. Totani found that animals which received tyrosine did not produce any more growth than those that were on the practically tyrosine-free ration, and concluded from these experiments that tyrosine is not essential for nutrition, thereby taking a stand opposite to Abderhalden.

Totani also found that, while tryptophane improves somewhat the deficient character of gelatin, surprisingly, tyrosine, which is not found in that protein, does not; also that the addition of phenylalanine produces no effect just like tyrosine. This strengthens his evidence, he believes, that tyrosine is an amino-acid unessential for growth and that phenylalanine can be transformed into hydroxy-phenylalanine or tyrosine.

There are several objections to Totani's work, the main being that his period of experimentation, 24 days, was altogether too short to get any idea of the possible outcome of such an investigation. Besides, as Totani admits himself: "It is, of course, an objection to my experiments that the actual amount of tyrosine left in the diet is uncertain." He claims he could detect only 0.3 per cent tyrosine, but that figure may be much higher and we do not know yet about the minimum requirements of that amino-acid for growth. Moreover, in his control ration his rats did not grow normally, and from the experience in this laboratory on the requirements of the water-soluble vitamine, Totani's alcoholic extracts of protein-free milk did not furnish enough of that factor in the diet. In his work on gelatin the records show loss of body weight in all cases. The addition of tyrosine brought no improvement, neither did the equivalent amount of phenylalanine, yet the investigator concludes that the latter may be transformed into the former.

The author believes that Totani's conclusions with regard to the possible synthesis of the benzene nucleus are unwarranted and are based on altogether inadequate data. On the contrary the experimental data here presented strongly suggest the indispensibility of tyrosine for growth. However, further experimental data are necessary to establish this point finally.

Reconsidering the supplementary value of protein-free milk, it is interesting to note that, although Osborne and Mendel claim they were unable to obtain a positive Millon's test on 2 or 3 gm. of preparations of protein-free milk (14) the author has repeatedly obtained positive tests for tyrosine in preparations of several tenths of a gm. of protein-free milk prepared exactly as described by Osborne and Mendel. The preparations contained only 0.60 to 0.65 per cent nitrogen, and, therefore, were certainly free from any notable amounts of casein or lactalbumin. When 28 per cent of the ration is made up of this protein-free milk the amount of tyrosine which may exist there either free or in peptide chain formation may be considerable.

SUMMARY.

1. Lactalbumin when fed as 12 and 18 per cent of a ration, carrying 2 per cent of the total protein in the form of nitrogen of unknown source in an alcoholic extract of wheat embryo to furnish the water-soluble vitamins, was found to be inadequate for growth.

2. When fortified with a weight of cystine equal to 1 per cent of that of the total protein, lactalbumin fed at an 18 and 12 per cent level was found to be of excellent nutritive value. Cystine, then, is the primary growth-limiting factor in that protein.

3. Lactalbumin, when fed at a 9 per cent plane of intake, even in the presence of 1 per cent of the total weight of the protein in the form of cystine, was found to be very deficient in nutritive value. However, when fortified in addition with tyrosine in amount equal to 5 per cent of the total protein, it was found to be of excellent nutritive value. Tyrosine, then, is the secondary growth-limiting factor in that protein.

4. Protein-free milk was found to have a total sulfur content of 0.2 per cent, the greater part of which is in organic form. The

results suggest that protein-free milk contains either cystine or organically bound sulfur which the animal organism can transform into cystine. Protein-free milk was found to give qualitative tests for tyrosine.

The author wishes to express his appreciation to Professor E. B. Hart and Professor H. Steenbock for many valuable suggestions and criticisms in connection with this work; also to Professor E. H. Farrington of the Dairy Department of the College of Agriculture for the splendid facilities offered him in the preparation of lactalbumin.

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OCCURRENCE OF INOSITE HEXAPHOSPHORIC ACID IN THE SEED OF THE SILVER MAPLE (ACER SACCHARINUM).

SIXTEENTH PAPER ON PHYTIN.

By R. J. ANDERSON.

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Station, Geneva.)

(Received for publication, June 21, 1920.)

INTRODUCTION.

In an earlier paper from this laboratory¹ it was shown that the seeds of the silver maple are rich in organic phosphorus. The organic phosphorus compound was isolated as a barium salt but when the former paper was published this substance had not been identified. The completion of the investigation was delayed owing to the war and only recently were we able to resume this work.

In the first part of the investigation some maple seed was used which had been powdered and extracted with ether during the summer of 1917. The barium salt of the organic phosphorus compound isolated from this material was purified and crystallized. The product thus obtained appeared to be identical with tribarium inosite hexaphosphate or tribarium phytate preparations previously described.² On analysis results were obtained which agreed more closely with barium inosite pentaphosphate than with inosite hexaphosphate. It has been claimed by Rather³ that the principal organic phosphorus compound existing in plant material is inosite pentaphosphoric acid and our results in this case apparently confirm this view. This was the first time, however, that we had isolated a substance having this composition.

¹ Anderson, R. J., *J. Biol. Chem.*, 1918, xxxiv, 509.

² Anderson, R. J., *J. Biol. Chem.*, 1914, xvii, 141, 151, 165.

³ Rather, J. B., *J. Am. Chem. Soc.*, 1918, xl, 523.

A second preparation was therefore made of the barium salt from freshly powdered maple seed. This seed had been gathered at the same time as the former material. The carefully purified and crystallized barium salt was analyzed and its composition was found to agree closely with that of tribarium inosite hexaphosphate.

This difference in results could only be explained as due to partial hydrolysis of the inosite hexaphosphate in the powdered maple seed. The powdered material after being extracted with ether had been kept in a well stoppered bottle for about 2 years. Comparative analyses of the total and inorganic phosphorus in the old and the freshly powdered material fully verified the assumption that partial hydrolysis had occurred in the old powdered maple seed, although it had been stored under ideal conditions and it contained only a very small percentage of moisture.

Careful analyses were made to determine whether the enzyme, phytase, was present in maple seed. We employed the same method as was used in connection with phytase in wheat bran.⁴ The small increase in inorganic phosphorus which was observed after digestion in water or dilute acids could hardly be ascribed to the influence of phytase. This enzyme must therefore be present in very minute amounts in maple seed, if it is not entirely absent.

EXPERIMENTAL.

First Preparation of Barium Salt.

The dry maple seed had been powdered and extracted with ether in 1917. Of this material 500 gm. were digested in 1,500 cc. of 1 per cent hydrochloric acid. The mixture was stirred occasionally and allowed to stand over night. It was then filtered through a layer of paper pulp on a Buchner funnel and washed with water until 2,000 cc. of extract were obtained. In order to bind the free hydrochloric acid 75 gm. of sodium acetate were added and the dissolved protein was precipitated by tannic acid. After filtering through paper pulp, 40 gm. of barium chloride in concentrated solution was added. The precipitate was filtered and washed in water.

⁴ Anderson, R. J., *J. Biol. Chem.*, 1915, xx, 483.

After suspending this precipitate in water the barium was removed by adding a slight excess of sulfuric acid. The barium sulfate was filtered off and the filtrate precipitated by adding a concentrated solution of copper acetate. The copper precipitate was filtered, washed free of sulfates with water, suspended in water, and decomposed with hydrogen sulfide. The copper sulfide was removed and the filtrate was concentrated to about one-half its volume under reduced pressure at a temperature of from 40–45°C.

The resulting acid solution was precipitated with barium hydroxide, filtered, and washed in water. The precipitate was dissolved in very dilute hydrochloric acid and again precipitated with barium hydroxide. The substance was reprecipitated in this manner five times from dilute hydrochloric acid by barium hydroxide. The product was then precipitated three times from dilute hydrochloric acid by adding about one and one-half volumes of 95 per cent alcohol, washing free of chlorides with dilute alcohol after each precipitation. After the substance was precipitated with alcohol a fourth time, it was allowed to stand in contact with the mother liquor for several hours when it changed into the usual crystalline form of tribarium phytate. The crystalline precipitate was filtered and washed free of chlorides with dilute alcohol. It was then dissolved in dilute hydrochloric acid as before and the free acid nearly neutralized by adding cautiously a dilute solution of barium hydroxide until a faint precipitate remained which did not dissolve on shaking. The mixture was filtered and a concentrated solution of 20 gm. of barium chloride was added to the clear filtrate. A heavy crystalline deposit of the barium salt separated slowly on the bottom of the flask. After standing over night this was filtered off and washed with water until free from chlorides. The substance was then recrystallized four times from dilute hydrochloric acid by the addition of alcohol. It was filtered and washed free from chlorides in 30, 50, and 95 per cent alcohol. It was then washed in ether and dried in vacuum over sulfuric acid. The product was a snow-white, bulky, crystalline powder which weighed 3.4 gm. Its dilute nitric acid solution gave no reaction with silver nitrate or with ammonium molybdate showing the absence of chlorides and inorganic phosphate.

The substance was analyzed after drying at 110° in vacuum over phosphorus pentoxide.

0.3168 gm. substance gave 0.0383 gm. H_2O and 0.0864 gm. CO_2 .
 0.1915 " " " 0.1268 " $BaSO_4$ and 0.1156 gm. $Mg_2P_2O_7$.
 Found: C, 7.43; H, 1.35; P, 16.82; Ba, 38.96 per cent.

The substance was again recrystallized three times from dilute hydrochloric acid by the addition of alcohol, filtered, washed, and dried as before.

After drying to constant weight as above it was analyzed.

0.2846 gm. substance gave 0.0335 gm. H_2O and 0.0735 gm. CO_2 .
 0.1838 " " " 0.1212 " $BaSO_4$ and 0.1103 gm. $Mg_2P_2O_7$.
 Found: C, 7.04; H, 1.31; P, 16.73; Ba, 38.80 per cent.

The product was again recrystallized in the same manner, washed, and dried, and the following result obtained on analysis.

0.2527 gm. substance gave 0.0306 gm. H_2O and 0.0675 gm. CO_2 .
 0.1919 " " " 0.1265 " $BaSO_4$ and 0.1160 gm. $Mg_2P_2O_7$.
 Found: C, 7.28; H, 1.35; P, 16.85; Ba, 38.79 per cent.

As recrystallization did not alter the composition of this substance it was undoubtedly pure. In crystal form and properties it appeared to be identical with the tribarium phytate isolated from other plant material but the analytical results do not agree with the theoretical composition of this salt. The carbon is too high and the phosphorus is too low. In fact, the analytical data agree more closely with the calculated composition of a mixed barium salt of inosite pentaphosphoric acid as is evident from the figures below.

For $(C_6H_{12}O_{21}P_5)_2 Ba_5$ or $C_{12}H_{24}O_{42}P_{10}Ba_5 = 1,837$.
 Calculated: C, 7.83; H, 1.30; P, 16.87; Ba, 37.40 per cent.
 Found (1): C, 7.43; H, 1.35; P, 16.82; Ba, 38.96 " "
 " (2): C, 7.04; H, 1.31; P, 16.73; Ba, 38.80 " "
 " (3): C, 7.28; H, 1.35; P, 16.85; Ba, 38.79 " "

When it was found that this preparation differed in composition from tribarium phytate by containing a higher percentage of carbon and less phosphorus it was thought that the organic phosphorus compound might have undergone some spontaneous hydrolysis. The old powdered maple seed was therefore examined

for total and inorganic phosphorus in comparison with a sample of freshly powdered material. The result showed that 18 per cent of the total phosphorus was present as inorganic while in the freshly powdered material only 12 per cent of the total was inorganic phosphorus. It is evident therefore that some hydrolysis of the organic phosphorus had occurred in the old powdered maple seed.

Second Preparation of the Barium Salt From Freshly Powdered Maple Seed.

The freshly powdered maple seed, 800 gm., was digested for 5 hours in 3 liters of 1 per cent hydrochloric acid. The organic phosphoric acid was isolated as the barium salt and recrystallized in the manner described above. A snow-white, bulky, crystalline powder was finally obtained. The substance was analyzed after drying to constant weight at 105° in vacuum over phosphorus pentoxide.

0.3210 gm. substance gave 0.0352 gm. H_2O and 0.0779 gm. CO_2 .
0.1705 " " " 0.1126 " $BaSO_4$ and 0.1044 gm. $Mg_2P_2O_7$.
Found: C, 6.61; H, 1.22; P, 17.06; Ba, 38.86 per cent.
For $C_6H_{12}O_{24}P_6Ba_3 = 1,066$.
Calculated: C, 6.75; H, 1.12; P, 17.44; Ba, 38.65 per cent.

The composition of this substance agrees closely with that of similar salts previously isolated from cotton-seed meal, oats, corn, commercial phytin, and wheat bran, which we have described.⁵ The analyses of these preparations, which have been carefully purified and recrystallized many times, are in close agreement with the calculated composition of a tribarium salt of inositol hexaphosphoric acid.

Judging by the analytical results obtained with these crystalline barium salts, the composition of phytic acid is most accurately represented by the formula of inositol hexaphosphoric acid, $C_6H_{18}O_{24}P_6$; and not by the formula of inositol pentaphosphoric acid, $C_6H_{17}O_{21}P_5$ or by other formulas as stated by Rather³ or by the formula $C_6H_{24}O_{27}P_6$ as stated by Posternak.⁶

⁵ Anderson,² p. 190.

⁶ Posternak, S., *Compt. rend. Acad.*, 1919, clxix, 37.

Hydrolysis of the Phytin from Maple Seed into Inosite and Phosphoric Acid.

The analyzed barium salt, 1.9 gm. was hydrolyzed with dilute sulfuric acid at 145° in an autoclave for about 2½ hours. The inosite was isolated in the usual way and after recrystallizing several times from water with the addition of alcohol 0.24 gm. of inosite was obtained which corresponds to 80 per cent of the theoretical yield. The inosite separated in the usual needle-shaped crystals; it gave the reaction of Scherer and it melted at 223° (uncorrected). Since the substance possessed the properties and gave the reactions of inosite the analysis was omitted.

Examination of Maple Seed for Phytase.

The freshly powdered maple seed was digested in the solvents mentioned in Table I as follows: Samples of 12.5 and 25 gm. were

TABLE I.
Inorganic Phosphorus in Maple Seed.

Solvent.	Inorganic phosphorus.
	<i>per cent</i>
Water	0.16
0.05 per cent HCl.	0.14
0.10 " " "	0.12
0.20 " " "	0.11
0.20 " " acetic acid	0.11
0.30 " " HCl.....	0.10
1.00 " " "	0.09

macerated with frequent shaking for 24 hours in 242.5 cc. of the solvent; 7.5 cc. of concentrated nitric acid were then added and the mixture was well shaken and allowed to stand for ½ hour. It was then filtered and the inorganic phosphorus was determined in aliquots representing 5 and 10 gm. of the sample by precipitating with ammonium molybdate in the usual manner and then with magnesia mixture. After it was filtered and ignited, the residue was taken up in dilute hydrochloric acid and reprecipitated as magnesium ammonium phosphate, incinerated, and weighed as magnesium pyrophosphate.

The results shown in Table I were obtained.

The increase in inorganic phosphate obtained on digesting the material in water or in the very dilute acid was so slight as to preclude the presence of an active phytase in maple seed.

SUMMARY.

An investigation has been made of the organic phosphorus compound of maple seed.

From an old sample of powdered maple seed a crystalline barium salt was obtained which corresponded to a barium salt of inosite pentaphosphoric acid, but from freshly powdered maple seed a crystalline barium salt corresponding to tribarium inosite hexaphosphate was obtained.

Evidence is presented which shows that some spontaneous hydrolysis of the organic phosphorus compound in maple seed occurs when the powdered material has been stored for about 2 years.

Freshly powdered maple seed apparently does not contain any active phytase.

The principal organic phosphorus compound of maple seed is identical with the inosite hexaphosphoric acid which has been isolated from other plant material.

AMINO-ACIDS OF THE BLOOD AS THE PRECURSORS OF MILK PROTEINS.*

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The formation of milk in the mammary glands of lactating cows is so rapid that a determinable reduction of the precursors of milk constituents in the blood which has passed through the glands may reasonably be expected. With this idea in mind, Kaufmann and Magne (1) have compared blood samples, obtained approximately simultaneously from the jugular and from the mammary (abdominal subcutaneous) veins of milking cows, and have found that the concentration of dextrose in the mammary blood is less than that in the jugular blood. They conclude that this difference is due to the utilization of dextrose by the mammary glands as the precursor of milk sugar.

In analogous experiments Meigs, Blatherwick, and Cary (2) have found that the phosphatide content of the mammary blood is lower than that of the jugular, and conclude that this material is the precursor of milk fat and milk phosphorus. Discussions of this method of determining the changes effected in blood as it passes through the mammary gland by comparing blood obtained from the mammary veins with that of other samples of venous blood (*e.g.* that from the jugular veins) and the reliability of results obtained in this way are to be found in the two articles to which reference has just been made.

It seems not unlikely *a priori* that the mammary gland may use the free amino-acids of the blood as the precursors of milk protein. Several fairly satisfactory methods of determining the amino-acid N of blood and blood plasma exist, and numerous determinations have been made with the blood of various species of animals.

* Published with the permission of the Secretary of Agriculture.

The amino-acid N of blood is uniformly very low compared with the protein content of milk. The conditions are, therefore, very favorable in this case for the success of experiments similar to those of Kaufmann and Magne. I have carried out such experiments with both dry and milking cows, comparing the concentration of amino-acid N in blood and plasma obtained approximately simultaneously from the jugular and mammary veins.

Analytical Method.

The amino-acid N in the amino-acid extract from the blood and plasma was determined by the HNO_2 method, using the smaller apparatus designed by Van Slyke (3). This amino-acid extract was prepared essentially according to the method recommended by Bock (4) with certain modifications. The procedure varied somewhat in the different experiments. That finally adopted was as follows:

Duplicate samples of 50 and 80 cc. of blood, and 80 and 100 cc. of plasma were measured out. 1 cc. of a freshly prepared 10 per cent aqueous extract of urease from jack bean meal¹ and 0.2 cc. of a 3 per cent solution of NaH_2PO_4 were added for each 10 cc. of sample. The mixture was allowed to stand about 2 to 3 hours at 30°C . to hydrolyze the urea.

The mixture was then run slowly into five volumes of boiling dilute acetic acid (0.0125 N for the blood and 0.015 N with the plasma samples), the original vessel was rinsed in, and the boiling with constant stirring continued for 5 minutes more. A volume of boiling water equal to about three times that of the sample was added, and the mixture boiled for about 5 minutes more. It was then transferred to a volumetric flask of about ten times the volume of the sample and brought to volume. (A drop or two of amyl or caprylic alcohol was used in the case of the blood samples to prevent a foam from interfering in bringing them to volume.) The mixture was then shaken vigorously for some time, the temperature taken, and the contents were filtered through a folded filter paper into a flask containing 2 gm. of finely powdered kaolin per 100 cc. of mixture to be filtered. The filtrate was pressed out of the residue on the paper as completely as convenient. It was then shaken up several times with the kaolin and, after standing for some time, was filtered through a No. 42 Whatman filter paper and then refiltered through a No. 44 Whatman paper. The filtrate thus obtained was perfectly clear and colorless. The temperature was taken and as large an aliquot as possible taken out.

¹ One part of finely powdered jack bean meal and ten parts of water were shaken together several times during an hour, centrifuged, and the supernatant liquid was pipetted off and used.

This aliquot was concentrated rapidly to about 10 cc. by boiling in a Kjeldahl flask through which a stream of air was passing. Only a slight amount of whitish sediment appeared. The concentrated solution with the sediment was transferred to a 50 cc. volumetric flask, 5 cc. of an aqueous solution of trichloroacetic acid² were added, and the whole was brought to volume. It was then poured upon 2 gm. of kaolin, shaken several times during an hour, centrifuged, and filtered through a No. 44 Whatman paper. The filtrate was perfectly clear. A 45 cc. aliquot was taken out.

This second aliquot was heated in a flask in a pan of boiling water for 3 hours. Either a long necked flask or a rubber stopper with a piece of glass tubing as a reflux was used to prevent concentration of the solution. After thus decomposing the trichloroacetic acid, the solution was transferred to an aerating cylinder. 4 cc. of a 10 per cent suspension of calcium hydroxide, a drop or two of a 0.5 per cent aqueous suspension of phenolphthalein, and about four drops of caprylic alcohol were added. The aeration was continued for about 3 hours. The mixture was then filtered into a small beaker, the cylinders and paper were washed with ammonia-free water, the filtrate and washings together neutralized with 50 per cent acetic acid, and an excess of two or three drops of this acid added.

The solution was then concentrated on an electric hot plate at just below the boiling point, and finally brought to 10 or 15 cc. in a volumetric flask. This was generally refiltered before running on the amino-acid apparatus.

In determining the amino-acid N on the Van Slyke apparatus with the extracts prepared as above, the evolution of N was never complete in the time allowed for the deamination of the α -amino N, which was 5 minutes at 25°C. In several different analyses of the same amino-acid extract, in which deamination times of 5, 10, and 15 minutes were allowed, it was found that the evolution of N (corrected for reagents) during the third 5 minutes was practically the same as that during the second 5 minutes. Hence it was assumed that this slowly evolved N came off at practically the same rate during the first 5 minutes, and a correction for it was accordingly made in all the analyses of extracts prepared as above described. Several determinations were made on each extract, allowing the shorter deamination time (sufficient for the reaction of the α -amino N to go to completion, and for about 95

² 100 cc. of solution contained 50 gm. of trichloroacetic acid. The protein would thus be precipitated in a 5 per cent concentration of trichloroacetic acid. In a private communication Dr. Bock recommends this concentration instead of that in his article (4).

per cent of the ϵ -amino group of lysine to come off), and several allowing a deamination time twice as long. For the slowly evolved N correction was made essentially as suggested by Van Slyke and Meyer (5), by subtracting the average (corrected for reagents) of the shorter runs from that of the longer and subtracting this difference from the former.

During the determination on the amino-acid apparatus with all the samples to be compared the temperature was kept constant. The samples for analysis were measured into the apparatus with a 2 cc. Ostwald pipette; and the various determinations of the jugular and mammary samples to be compared were run alternately on the machine, so as to keep the conditions as nearly comparable as possible.

Throughout the whole procedure a jugular sample and a corresponding mammary sample of the same size were run as a pair under as nearly the same conditions as possible.

The amino N was determined in the urease extract used in each experiment by the same method as above, and correction was made for it accordingly.

Each datum, therefore, with each of the duplicate samples of blood or plasma given in Table II of this article, is the average of several determinations on the amino-acid apparatus corrected for (1) the reagents used, (2) any slowly evolved N, and (3) the amino N of the urease used.³

EXPERIMENTAL.

My results are summarized in Table I. More detailed data are given in Table II and its accompanying note.

³ The figures for amino-acid N that I have obtained from the blood and plasma of cows are considerably lower than those of Bock (6) and Okada (7) from beef animals, although they used an analytical procedure essentially the same as that which I have followed, but they do not state what corrections enter into the calculation of their results or whether they corrected for the amino-acid N of the soy bean meal that they used.

TABLE I.

Average Amino-Acid N in Blood and Plasma, and Difference in Plasma Samples.

Experiment No. Cow No. Date.	Average amino-acid N per 100 cc.				Difference in plasma samples.		Milk yield daily.
	Blood.		Plasma.		Amount.	Per cent of jugular.	
	Jugular.	Mam- mary.	Jugular.	Mam- mary.			
1919	mg.	mg.	mg.	mg.	mg.	per cent	liters
I 51 Sept. 19			2.69	1.78	0.91	33.8	12 77
II 51 Sept. 26			3.31	2 34	0.97	29.3	12 55
III 64 Oct. 15	4 49	4 32	2.49	1 92	0.57	22.9	8.70
IV 51 Nov. 28	4 01	3 83	2 38	1 99	0 39	16.4	9 88
V 51 Dec. 8	4 19	3 91					9 69
VI 51 Dec. 15			2.47	1.87	0.60	24.3	9.65
1920							
VII 56 Feb. 2	3.99	3.92	2.14	2.20			Dry.
VIII 63 Feb. 17			2.40	2.51			"
IX 227 Mar. 2	5.34	.58	3.02	2.35	0.67	22.2	25.14

TABLE II.

Data from Experiments on Both Dry and Milking Cows.

Experiment No. Cow No. Date	Corpuscle volume.		Amino N per 100 cc.				Milk yield daily.	Crude protein N of daily diet.
	Jugular.	Mammary.	Blood.		Plasma.			
			a. Jugular 1. b. Jugular 2. c. Average.	a. Mammary 1. b. Mammary 2. c. Average.	a. Jugular 1. b. Jugular 2. c. Average.	a. Mammary 1. b. Mammary 2. c. Average.		
1910	per cent	per cent	mg.	mg.	mg.	mg.	liters	gm.
I 51 Sept. 19					a. 2.66 b. 2.72 c. 2.69	a. 1.67 b. 1.89 c. 1.78	12.77	188.1
II 51 Sept. 26	32.1	30.3			a. 3.47 b. 3.15 c. 3.31	a. 2.38 b. 2.31 c. 2.34	12.55	188.1
III 64 Oct. 15	36.75	36.0	a. 4.49 b. 4.03 c. 4.01	a. 4.32 b. 3.81 c. 3.83	a. 2.30 b. 2.68 c. 2.49	a. 1.78 b. 2.07 c. 1.92	8.70	162.8
IV 51 Nov. 28	31.6	31.6	a. 3.99 b. 4.03 c. 4.01	a. 3.85 b. 3.81 c. 3.83	a. 2.42 b. 2.34 c. 2.38	a. 2.10 b. 1.89 c. 1.99	9.88	164.7

* In Experiments I to VI inclusive, the urea and ammonia were not removed and the samples for duplicate analyses on the amino-acid apparatus were measured in from the burette on the side of the apparatus. In Experiments I to IV inclusive, with the exception of the plasma samples of Experiment IV, the filtrate from the heat-acetic acid coagulation was not shaken with kaolin.

In Experiments I to III inclusive, the deamination times were 4 and 8 minutes at temperatures of 21–25°C. In Experiments IV and V the deamination times were 5½ and 8½ minutes with temperatures from 19.5–24°C. In Experiment VI, the deamination times were 4 and 8 minutes at 27–28°C., and in Experiments VII to IX, inclusive, the times were 5 and 10 minutes at temperatures from 25–27°C. In Experiments I to VI inclusive the several analyses on the amino-acid apparatus of each blood or plasma duplicate were run off consecutively instead of alternating with the sample to be compared with it, as described above.

TABLE II.—Continued.

Experiment No. Cow No. Date.	Corpusele volume.		Amino N per 100 cc.				Milk yield daily.	Crude protein N of daily diet
	Jugular.	Mammary.	Blood.		Plasma			
			a Jugular 1 b Jugular 2 c Average	a Mammary 1 b Mammary 2 c. Average.	a Jugular 1 b Jugular 2 c. Average.	a Mammary 1 b Mammary 2 c. Average		
1919	per cent	per cent	mg.	mg	mg.	mg	liters	gm
V 51 Dec. 8			a. 4 19	a. 3 91			9 69	164 7
VI 51 Dec. 15	32 3	31.4			a. 2 47 b. 2.48 c. 2 47	a. 1 85 b. 1.89 c. 1 87	9 65	164.7
1920								
VII 56 Feb. 2	30.8	30.4	a. 3.99	a. 3 92	a. 2.18 b. 2 10 c. 2 14	a. 2.16 b. 2 25 c. 2.20	Dry since Oct., 1918.	127.0
VIII 63 Feb. 17	35.2	33 9			a. 2.44 b. 2 37 c. 2.40	a. 2 52 b. 2 51 c. 2 51	Dry since July 12, 1919.	82.6
IX 227 Mar. 2	33 0	30.7	a. 5 39 b. 5 30 c. 5.34	a. 4 65 b. 4.51 c. 4 58	a. 3 04 b. 3.00 c. 3.02	a. 2.35 b. 2.35 c. 2.35	25.14	388 0

Details of Experiments.

Table II gives the details and data obtained in the experiments that I have tried with both dry and milking cows. The milk yield is the average of 3 days, including one before and one after the day on which the samples of blood were taken. All the cows were given their morning feed at the customary time, between 4 and 5 a.m. The samples of blood were generally taken between 8.30 and 9.15 a.m. The sample from the mammary vein was always taken first.

The area over the vein was bathed with a 5 per cent solution of phenol, sometimes some of the hair was clipped away, and then a trocar and cannula were inserted into the vein. Generally the cow

was not disturbed more than about 2 minutes before the flow of blood was secured. About 1 to 3 minutes were required to collect the mammary sample. About 2 minutes intervened before the flow of jugular blood was obtained and 1 to 2½ minutes were required to collect this sample. The samples varied from 200 to 650 cc. There was no relation between the size of sample and the data obtained. The samples were collected in bottles containing 0.1 gm. of dry sodium oxalate per 100 cc. of blood to be taken.

The plasma was obtained immediately by centrifuging the blood for 20 minutes at 3,600 revolutions per minute. The corpuscle volume was noted on a graduated centrifuge tube.

The analytical procedure was that described above except as indicated in the footnote to Table II.

Table II includes all the data that I have obtained except: (1) the first two experiments that I made, in which the analytical methods subsequently used were not fully worked out; (2) one subsequent experiment in which my procedure was varied and in which the duplicates did not agree at all; and (3) the blood determinations of Experiment VI, which were made by several different methods that did not give concordant results. The duplicate blood determinations in Experiments III, V, and VII were lost.

I was unable to note any relation between the apparent disturbance of the cows and the variations in the amino-acid N of the blood and hence have omitted the details bearing upon this point.

DISCUSSION.

In the six experiments with milking cows, the amino-acid N of the mammary plasma is decidedly lower than that of the jugular, the differences varying from 0.39 to 0.97 mg. per 100 cc. of plasma in the different experiments. In the four experiments with milking cows in which the amino-acid N of the whole blood was determined it is lower in the mammary than in the jugular blood, although the differences are sometimes small. In the experiments with dry cows, the jugular and mammary samples of both blood and plasma are practically identical.

In Table III the maximum absolute difference between the duplicates is compared with the difference between the jugular and mammary averages in the case of the plasma determinations in each experiment.

In all the experiments on milking cows the differences in the amino-acid content of the jugular and mammary samples of plasma are greater than the maximum differences between the duplicates. The results, as a whole, furnish conclusive evidence for the view that the mammary plasma of milking cows contains decidedly less amino-acid N than the jugular plasma.

The differences between the amino-acid N contents of the jugular and mammary samples of blood in my experiments were generally less, not only relatively but absolutely, than the corresponding differences in the samples of plasma. The greater plasma

TABLE III.

Maximum Absolute Difference between Duplicates Compared with Difference between Jugular and Mammary Plasma Averages.

Experiment No.	Maximum difference in plasma duplicates.	Difference between jugular and mammary plasma averages.		Milk yield daily.
		Mammary less	Mammary greater	
	<i>mg.</i>	<i>mg.</i>	<i>mg.</i>	<i>liters</i>
I	0.22	0.91		12.77
II	0.32	0.97		12.55
III	0.38	0.57		8.70
IV	0.21	0.39		9.88
V	No plasma determinations.			
VI	0.04	0.60		9.65
VII	0.09		0.06	0.00
VIII	0.07		0.11	0.00
IX	0.04	0.67		25.14

differences probably mean that the amino-acids of the blood corpuscles take no part in the interchange which goes on between the blood and the mammary gland and that there has been no migration of amino-acids from the corpuscles to the plasma of the samples of blood between the time that they were collected and the time that they were centrifuged. In view of these circumstances, I shall consider only the amino-acids of the plasma in attempting to compare the reduction of the concentration of these compounds in the mammary samples with the amount of protein secreted by the mammary gland in a given time.

There have been no definite determinations of the flow of blood through the mammary gland. It has been roughly estimated by

Meigs, Blatherwick, and Cary (2) from the data of Kaufmann and Magne (1) that with a cow giving 10 liters of milk daily about 3.5 liters of blood pass through the mammary glands per minute. The largest difference in amino-acid N that I have determined between the jugular and mammary plasma was nearly 1 mg. per 100 cc. in Experiment II with No. 51. She was giving 12.55 liters of milk daily. The corpuscle volume of the jugular blood was about 32 per cent. If it is assumed that the blood flow through her gland was at the rate of 3.5 liters per minute, this would mean that the flow of plasma amounted to about two-thirds of this figure, or 2.3 liters per minute.

If milk secretion goes on continuously throughout the 24 hours, as suggested by Meigs, Blatherwick, and Cary (2), about 33 gm. of α -amino-acid N, according to the result in this experiment, would be abstracted daily by the mammary gland from the plasma of the blood perfusing it. The α -amino N of the milk proteins is about 70 per cent of their total N. Hence the amino N thus taken up from the plasma of the blood daily would be equivalent, in this experiment, to about 300 gm. of milk protein or a protein content of the milk of 2.4 per cent. This estimate is very rough. It indicates, however, that the differences are roughly of approximately sufficient magnitude to account for the secretion of milk protein.

An interesting feature of the work which remains to be discussed is the result obtained in Experiment IX. The subject of this experiment was giving about 25 liters of milk daily—from two to two and a half times that given by the other milking cows. But in spite of this, the absolute decrease in the amino-acid N of the mammary plasma was practically the same as the average absolute decrease for the other milking cows. This result may be interpreted to mean that as a general rule the flow of blood through the mammary gland is proportional to the milk yield. There is a good deal of evidence to support this view (2).

The CO₂ Capacity of Jugular and Mammary Plasma. •

Dr. N. R. Blatherwick has determined the CO₂ capacity of the jugular and mammary plasma in some of the experiments reported above. With his permission, I am including these data in Table IV.

As far as the above data go, it would seem that the following observations are justified.

1. The CO₂ capacity of the plasma of the blood from the inactive mammary gland is somewhat greater than that of the plasma from the jugular blood.

2. The difference in CO₂ capacity as between the jugular and mammary plasma of milking cows is relatively greater than that in the case of the non-lactating cow.

TABLE IV.
CO₂ Capacity of Jugular and Mammary Plasma.

Experiment No. Cow No. Date.	CO ₂ capacity in volumes.		Milk yield daily.
	Jugular.	Mammary.	
<i>1919</i>	<i>per cent</i>	<i>per cent</i>	<i>liters</i>
III 64 Oct. 15	64.5	69.2	8.70
IV 51 Nov. 28	65.5	70.2	9.88
<i>1920</i>			
VIII 63 Feb. 17	59.5	61.4	0.00
IX 227 Mar. 2	69.1	72.0	25.14

3. If we compare the differences in CO₂ capacity obtained from Nos. 51 and 64 with that from No. 227, there are two possibilities: The CO₂ capacity of the arterial blood was already high in the case of No. 227 as indicated by the CO₂ capacity of the jugular plasma, and it may be that the increase in CO₂ content of the blood passing through the mammary gland did not therefore effect relatively so great a change in CO₂ capacity; or, second, it may be that the metabolism indicated by this increased CO₂ capacity in the mammary plasma is not proportional to the milk yield and

therefore in the high producing cow is less relative to the flow of blood through the gland.

A calculation of the CO_2 output of the mammary gland from the data at hand would involve several more or less unsupported assumptions and hence would not be very reliable.

SUMMARY.

1. The amino-acid N of the blood and blood plasma obtained from the mammary vein in non-lactating cows is practically the same as that obtained from the jugular vein.

2. The amino-acid N of blood and blood plasma obtained from the mammary vein in milking cows is decidedly lower than that obtained from the jugular. The mammary plasma has been found to contain from 16 to 34 per cent less amino-acid N than the jugular plasma.

3. The amino-acids thus picked up by the mammary gland from the plasma of the blood perfusing it are sufficient to account for the proteins of the milk and are undoubtedly the precursors of these milk constituents.

4. Data are presented on the CO_2 capacity of the plasma of blood from the jugular and mammary veins of milking and dry cows.

In conclusion, I desire to express my sincere appreciation of the suggestions and kindly interest in the work of Dr. E. B. Meigs and Dr. N. R. Blatherwick, of this laboratory, and Mr. T. E. Woodward, Superintendent of the Dairy Division Farm at Beltsville, Md., where this work was conducted.

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STUDIES ON CARBOHYDRATE METABOLISM IN RABBITS.

I. OBSERVATIONS ON THE LIMITS OF ASSIMILABILITY OF VARIOUS CARBOHYDRATES.*

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In the advertising literature of a well known proprietary food for infants and invalids, the statement is made that this product, which is said to be a mixture of dextrin and maltose prepared by the action of malt diastase on the starch of cereals, is "100 per cent more assimilable than either milk or cane sugar." Upon investigation it was found that this statement was based on a paper by Lovett, Morse, and Talbot,¹ who quoted the limits of assimilation of the different sugars recorded by various investigators as follows:

"Grape Sugar: In babies, about 5 grams per kilo (Langstein and Meyer).

Grape Sugar: In one-month baby, 8.6 grams per kilo (Greenfield).

Galactose: No accurate data.

Levulose: Lower for babies than adults. One gram per kilo (Keller).

Maltose: Over 7.7 grams per kilo (Reuss).

Lactose: 3.1-3.6 grams per kilo (Grosz).

Cane Sugar: About the same as lactose (Reuss)."

* The data in this paper were taken from the dissertation presented by Martha R. Jones for the degree of Doctor of Philosophy, Yale University, 1920. Part of the expense of the investigation was defrayed by a grant from the Russell H. Chittenden Research Fund for Physiological Chemistry.

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¹ Lovett, R. W., Morse, J. L., and Talbot, F. B., *Boston Med. and Surg. J.*, 1911, clxiv, 852.

A perusal of the scanty literature on the subject of alimentary sugar tolerance showed that the figures quoted had been obtained from a comparatively few isolated experiments which had been performed by various investigators using different methods and under totally different conditions. Since data of this sort are in no way comparable, more evidence seemed necessary before definite conclusions could be drawn in regard to the relative assimilability of sugars. In view of the very extensive use of carbohydrates of various kinds in dietaries of infants, and the uncertainty of the medical profession in regard to their relative values, the present investigation was planned to study the question under conditions involving as few variables as possible.

In clinical practice sugar tolerance is considered to be the largest number of grams of glucose which can be ingested at one time without causing glycosuria. The alimentary method of determining tolerance obviously has its limitations, since the entry of the sugar into the blood depends not only upon the motor power of the stomach and intestines, but also on the rate of absorption which varies with a wide range of conditions. Real tolerance, as Woodyatt, Sansum, and Wilder² remind us, depends upon the rate at which the tissues are able to abstract glucose from the blood and utilize it. Sugar introduced directly into the circulation does not have to undergo absorption, hence the rate of injection can be so regulated that it is just equal to the rate at which the blood and tissues will bind and hold the sugar without an overflow through the kidneys. From this standpoint, glucose tolerance signifies the largest number of grams per kilo of body weight per hour which can be injected into a vein without causing glycosuria. Since the sugars in which we are primarily interested are constituents of foods, it seemed that the oral method of studying tolerance was preferable for our purposes, and hence this method was selected.

Feeding and Analytical Technique.

Rabbits were used: seven females and ninety-six males. They were divided into groups and kept in large pens. Free access to corn, oats, and water was had at all times, and fresh cab-

² Woodyatt, R. T., Sansum, W. D., and Wilder, R. M., *J. Am. Med. Assn.*, 1915, lxx, 2067.

bage, in limited quantities, was fed daily. This diet was always relished and was sufficiently well balanced to keep the animals in good nutritive condition over a long period of time. One rabbit was kept during the entire experimental period of 9 months and within that time received forty doses of sugar without showing ill effects.

The rabbits were usually taken from the pens on the afternoon before they were to be used, and placed in metabolism cages in which there was an abundance of oats and water. The next morning each animal was weighed and the normal urine collected by compressing the abdominal wall over the bladder. The urine was tested qualitatively for reducing substances with Benedict's reagent, and if the reaction was negative the rabbit was fastened on the animal board and the sugar solution administered by means of a stomach sound. Great care was exercised to excite the animals as little as possible, and with very few exceptions they neither offered resistance nor exhibited fear.

Sugar solutions were made up to a volume of 50 cc. except in a few cases where the concentration was so great that the liquid could not run through the tube. In such cases the volume was increased to as much as 65 cc. After the administration of the sugar the rabbits were returned to their cages where they had free access to oats, cabbage, and water. Since cabbage contains some sugar, this probably introduced a source of error, but the amount eaten after the ingestion of the carbohydrate solution was usually quite small, and hence the error was negligible. After an interval of $3\frac{1}{2}$ hours the urine was again collected and tested qualitatively with Benedict's reagent. Since we were not concerned with mere traces of reducing substances, all tests which were not definitely positive were recorded as negative. As used in these experiments, Benedict's reagent showed a positive reduction when glucose was present in a concentration of 0.08 per cent. Early in the investigation the animals were always kept in their metabolism cages for 24 hours after the ingestion of the carbohydrate solution and the total urine voided during this time was tested, but it was invariably found that if sugar appeared at all the greater portion was excreted during the first $3\frac{1}{2}$ hours; hence, this procedure was discontinued. Frequent confirmatory osazoné and fermentation tests were made. If the

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test was negative, the dosage of sugar was increased 1 to 3 gm. per kilo until sugar appeared in the urine. *The smallest amount of carbohydrate which resulted in glycosuria was recorded as the assimilation limit.* In sucrose experiments and frequently after the ingestion of maltose and dextrin the urine was made acid (1 per cent) with HCl, hydrolyzed for 30 minutes in a boiling water bath, cooled, neutralized, and tested again for sugar. Doses were repeated at intervals of 48 hours until each animal had received three. During this time the rabbit was kept in its metabolism cage and at the end of the period was returned to the large pen where it remained for a week or more. In order to determine whether repeated doses of sugar had any effect upon tolerance, some of the animals were divided into groups and the order of administration varied.

Early in the investigation sucrose solutions were given and much difficulty was experienced in obtaining consistent results. It was noticed that unfiltered normal urine would often reduce Benedict's solution while the filtered urine would not. All urine was then filtered through ordinary filter paper. Frequently the first few drops of the filtrate were tested and these sometimes would reduce Benedict's solution while the mixed filtrate before and after inversion would not. Upon investigation it was found that after repeated doses of sucrose, an enzyme was excreted in the urine which acted upon the starch in the filter paper and produced sufficient sugar to cause a reduction of Benedict's solution. Following this discovery the urines were heated on a water bath for 2 or 3 minutes before filtering and the procedure continued as before. No discrepancies were observed after this precaution. In making so large a number of reduction tests with Benedict's solution, more uniform results were obtained by heating the tubes in boiling water for 6 minutes than by boiling each separately over a free flame; hence, this method was adopted.

Feeding Experiments with Carbohydrates.

Sucrose.—The limit of assimilability of sucrose was determined in twenty-two animals, the doses which just produced glycosuria ranging from 4 to 9 gm. per kilo. Thirteen of these animals had a marked increase in reducing sugar in the urine after inversion, indicating the presence of sucrose. Two rabbits which excreted reducing sugar after the ingestion of 6 and 7 gm. per kilo of sucrose, respectively, excreted sucrose, as such, when the dosage was increased 1 gm. per kilo each. To another rabbit in which

the assimilation limit was 9 gm. per kilo, sucrose appearing in the urine, a dose of 10.5 gm. per kilo was administered, the apparatus being so adjusted that the animal received 1 cc. of solution or 0.23 gm. per kilo of sugar per minute. Now the urine test was positive, but only reducing sugar was present. Eight of the fifty-eight animals receiving sucrose developed diarrhea, but in seven of these cases the dose exceeded the assimilation limit. Six of the eight cases of diarrhea were accompanied by sucrosuria. One animal had diarrhea after the ingestion of a dose smaller than the assimilation limit, but at a later time a much larger dose did not result in intestinal disturbances. No effort was made in any of these cases to determine the presence of sugar in the feces.

TABLE 1.

Animal No.	Limits of assimilability per kilo.	
	Sucrose.	Inverted sucrose.
	gm.	gm.
4	5	5
19	8	8
21	5	7 (Diarrhea.)
22	8 (Diarrhea.)	8 —
24	8	8 +
51	8 —	8 (Diarrhea.)
52	6	8 +
65	7	9
66	5	8
68	9	9
71	6	7
72	6	7
75	6	7
77	6	8

Plus and minus signs, wherever used, indicate that the limit of assimilability was not determined but was greater or less, respectively, than the figure given.

Inverted Sucrose.—Sucrose solutions were made up to a volume of 50 cc., made acid (1 per cent) with HCl, and heated on a boiling water bath for 30 minutes. They were then cooled, neutralized with NaOH, made up to a volume of 50 cc. with distilled water, and administered as previously described. The limits of assimilation

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lability of the invert sugar ranged from 5 to 9 gm. per kilo in eleven animals.

Table I shows the limits of assimilability of sucrose and inverted sucrose in the same animals.

In only one case, Rabbit 22, was the assimilability of the inverted sucrose less than that of sucrose. In fact, with the exception of Rabbit 22 in which the limit of assimilability of inverted sucrose was not determined, the average tolerance for inverted sucrose in the animals given above was more than 7.6 gm. per kilo, while the same animals had a tolerance of less than 6.5 gm. for sucrose. Three rabbits (Nos. 4, 19, 68) showed the same tolerance for inverted sucrose as for sucrose, while the remaining ten exhibited a greater tolerance for the inverted sugar. Two of the animals which had the same tolerance for sucrose as for inverted sucrose, had only reducing sugar in the urine after the ingestion of sucrose. Evidently, in these cases, the sugar was inverted in the intestines before absorption. Three rabbits which had a greater tolerance for inverted sucrose than for sucrose had sucrosuria. It would seem from these experiments that sucrose may be quite as rapidly absorbed as the mono-saccharides, and since the rabbit has no sucrase in its normal serum the tissues are unable to utilize it and it is excreted by the kidneys.

Levulose.—The limit of assimilability of levulose was determined in nine animals, the doses ranging from 3 to 10 gm. per kilo. Rabbit 24 received 14 gm. per kilo without sugar appearing in the urine. Diarrhea occurred only once after levulose ingestion, the animal receiving 9 gm. per kilo, but no sugar appeared in the urine.

Table II shows the relative assimilability of sucrose and levulose in the same animals.

Seven of the nine rabbits showed a tolerance for levulose equal to or greater than that for sucrose, while two had a slightly greater tolerance for sucrose.

Glucose.—In fourteen rabbits the limits of assimilability of glucose ranged from 10 to 16 gm. per kilo. Six of the eighteen animals which received glucose developed diarrhea, but in three of these cases the assimilation limit was exceeded. In one case a dose of 10 gm. per kilo resulted in diarrhea without sugar

appearing in the urine. A few days later this animal received a dose of 12 gm. per kilo. Sugar appeared in the urine but the feces were normal. Three animals had glucosuria without diarrhea after the ingestion of 16 gm. per kilo.

Table III gives the comparison of glucose tolerance with that of sucrose and levulose in the same animals.

TABLE II.

Animal No.	Limits of assimilability per kilo.	
	Sucrose.	Levulose
	<i>gm.</i>	<i>gm.</i>
4	5	3
19	8	8
21	5	9
22	8	10
23	4 —	7 +
24	8	14 +
40	5	5 —
49	8 —	9 +
52	6	10

TABLE III

Animal No.	Limits of assimilability per kilo.		
	Sucrose.	Glucose.	Levulose.
	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>
4	5	14	3
19	8	12	8
21	5	12 (Diarrhea.)	9
23	4 —	12	7 +
24	8	14 (Diarrhea.)	14 +
40	5	12 +	5 —
70	7	12	(?)

An examination of Table III shows that glucose tolerance was invariably higher than that of sucrose, and with one exception (Rabbit 24) was higher than that of levulose.

Lactose.—Four rabbits received doses of lactose ranging from 6.4 to 9 gm. per kilo without the appearance of sugar in the urine or diarrhea. Since it was found impossible to keep this quantity of sugar in solution in a volume of 50 cc., we decided to discon-

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tinue the test rather than introduce another variable into our experiments.

Maltose.—The limit of assimilability of maltose was determined in six animals. Two showed glycosuria after the ingestion of 10 and 14 gm. per kilo respectively, although the average tolerance of the remaining four was 19.5 gm. Doses ranging from 16 to 20 gm. per kilo were fed to seven rabbits without sugar in the urine or diarrhea resulting.

Dextrin.—Nineteen rabbits received doses of dextrin ranging from 15 to 20 gm. per kilo without exhibiting glycosuria, while the limit of assimilability was determined in only four. Rabbit 15 had a dextrin tolerance of 5.5 gm. per kilo. This animal exhibited relatively low tolerance for all carbohydrates and was the only one in which the limit of assimilability of dextrin was as low as that of sucrose. The average tolerance of the remaining three rabbits was 16.1 gm. per kilo. Occasionally the urine collected after the ingestion of dextrin was hydrolyzed and tested for sugar, but at no time was there an appreciable increase in reduction.

Dextri-Maltose.—The limits of assimilability of the carbohydrates ordinarily used in infant feeding having been determined, it seemed desirable to study the effect of various mixtures upon tolerance. Two commercial products, dextri-maltose (Mead's) and malt sugar (Borchardt's), were selected. Dextri-maltose is reported³ to contain 52.0 per cent maltose, 41.7 per cent dextrin, 2.0 per cent sodium chloride, and 4.3 per cent moisture, and is used as a food for infants and invalids. This preparation was fed to thirty-nine rabbits, twenty-one of which had an average tolerance of 14.5 gm. per kilo, while in eighteen the limit was not determined. Two animals received doses of 21 gm. per kilo without the appearance of sugar in the urine. Several tolerated as much as 18 gm. per kilo without glycosuria, while the limit of assimilability in one was only 6 gm. per kilo and in two others, less than 9. Rabbit 2 received a dose of 13 gm. per kilo, and 45 minutes later a second dose, 14 gm. per kilo, was administered. Neither the urine collected immediately before nor 3½ hours after the ingestion of the second dose con-

³ New and Non-official Remedies, 1919.

tained sugar. Several weeks later, this animal tolerated 22 gm. per kilo of this preparation without exhibiting glycosuria.

Malt Sugar.—Borcherdt's malt sugar which is also a food for invalids and infants is reported³ to contain 87.0 per cent maltose, 4.35 per cent dextrin, 1.9 per cent inorganic salts, and 4.4 per cent protein. This product was used with the view of ascertaining whether different proportions of dextrin and maltose would have any effect upon the assimilability of the mixture. Twenty-seven animals received doses of this preparation. In eleven rabbits the

TABLE IV.

Animal No.	Limits of assimilability per kilo.	
	Dextri-maltose.	Malt sugar.
	gm.	gm.
4	13.0	16.0
7	9.5	12.5
9	11.5	16.0
10	19.0	20.0 +
12	11.0	15.5 +
14	9.0	13.5
15	6.0	8.0
16	9.5	12.0
18	11.0	11.0 +
19	12.0	18.0
21	9.0 -	16.0
23	13.0	15.0
34	18.0 -	18.0 +
38	18.0	18.0 +
39	18.0	19.0

tolerance ranged from 8 to 19 gm. per kilo, although in twelve other animals doses ranging from 15 to 20 gm. per kilo did not result in glycosuria.

Table IV shows the relative assimilability of the two preparations in the same animals.

An examination of Table IV shows that all fifteen of the animals which received doses of the two commercial preparations had a greater tolerance for malt sugar than for dextri-maltose. Rabbit 19 assimilated 6 gm. per kilo more of malt sugar than of dextri-maltose, no diarrhea resulting in either case, while Rabbit 21 tolerated at least twice as much of the former as of the latter.

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Numerous investigators have shown that the addition of meat to sugar increases the tolerance for the latter, and the presence of protein in malt sugar might account for its greater assimilability. Five cases of diarrhea without glycosuria occurred after the ingestion of malt sugar, the doses ranging from 18 to 19 gm. per kilo. Six cases of diarrhea resulted after the ingestion of dextri-maltose, the doses ranging from 11 to 20 gm. per kilo. With one exception, no sugar appeared in the urine. Rabbit 35 had three doses, 15, 18, and 20 gm. per kilo, respectively, of dextri-maltose, all of which resulted in diarrhea, but sugar appeared in the urine only after the ingestion of 20 gm. per kilo. From these experiments, it would seem that the rate of absorption of the two preparations is relatively slow.

Maltose + Dextrin.—The next step in the investigation was the determination of the tolerance for known mixtures of carbo-

TABLE V.

Animal No	Limits of assimilability per kilo.			
	Maltose.	Dextrin.	Dextri-maltose	Maltose + dextrin
	gm.	gm.	gm.	gm.
4	17.5 +	16.0 +	13.0	14.0
9	20.0 -	11.5 +	11.5	
10	19.0		19.0	
12	21.0	8.0 +	11.0	
15	10.0	5.5	6.0	
19		18.0 +	12.0	
21		18.0	9.0 -	
23	18.0		13.0	13.0
34	20.0 +	17.5 +	18.0 -	
35	20.0 +	18.0 +	20.0	
65	16.0 +			16.0
66	16.0 +			16.0

hydrates. The limits of assimilability of dextrin and maltose mixed in the proportion of 1:1 ranged from 13 to 16 gm. per kilo in four animals, the average tolerance being approximately the same as that for dextri-maltose.

Table V shows the relative assimilability of maltose, dextrin, dextri-maltose, and a mixture of equal parts of maltose and dextrin in the same animals.

It appears that the tolerance for dextri-maltose and the dextrin-maltose mixture was less than that for either pure maltose or pure dextrin.

Sucrose + Dextrin.—Since rabbits have a very high tolerance for dextrin and a relatively low tolerance for sucrose, it was expected that the assimilation limit of a mixture of the two carbohydrates would lie somewhere between the limits of dextrin and sucrose; hence, a series of experiments was planned to study the behavior of sucrose-dextrin mixtures.

TABLE VI.

Animal No	Limits of assimilability per kilo.		
	Sucrose	Sucrose + dextrin.	Dextrin
	gm.	gm.	gm.
4	5.0	6 0	16 0 +
19	8 0	7 0 —	18 0 +
21	5.0	8.0	
23	4.0 —	8.0	
24	8 0	8.0	
35	8 0 —	9 0	
36	6 5	5 5 —	16 5 +
39	7.0	6 0 —	17 0 +
40	5.0	6 0	18 0
44	9 0	8.0 —	
65	7 0	7.0 —	
66	5 0 —	5.0	
68	8 0	9 0 —	18.0 +
70	7.0	7.0 —	16.0
71	6 0 —	5.0	
72	6 0 —	5 0 —	
73	8 0	7 0	

A solution consisting of equal parts of dextrin and sucrose was used. The assimilation limits in nine animals ranged between 5 and 9 gm. per kilo. Thirteen other rabbits received two or more doses of the mixture, but the smallest dose ingested by each still resulted in glycosuria.

The limits of assimilability of sucrose, dextrin, and sucrose + dextrin (1:1) in the same animals are given in Table VI.

An examination of Table VI shows that the assimilation limit of the mixture was less than that of sucrose alone in seven

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cases, while the reverse was true in six cases. Dextrin tolerance was, without exception, two or three times greater than that of either pure sucrose or the mixture of sucrose and dextrin. Seven rabbits (Nos. 4, 19, 36, 39, 40, 68, and 70) had an average dextrin tolerance of more than 17.07 gm. per kilo and an average sucrose tolerance of 6.64 gm., while less than 6.64 gm. of the sucrose-dextrin mixture was assimilated perfectly. Thirty-one rabbits had glycosuria after the ingestion of the sucrose-dextrin mixture and of these, twenty-five had sucrose in the urine; six had reducing sugar, and two had both.

Glucose + Dextrin.—A series of experiments was planned to determine whether the addition of dextrin to glucose has any

TABLE VII.

Animal No.	Limits of assimilability per kilo.		
	Glucose.	Dextrin.	Glucose-dextrin (1:1).
	gm.	gm.	gm.
4	14.0	16.0 +	10.0
19	12.0	18.0 +	16.0
21	12.0	18.0	15.0
69	16.0 +	16.0 +	16.0
74	10.0		14.0 +
78	16.0	18.0 +	16.0
79	16.0	16.0 +	16.0 +

effect upon the tolerance of the latter. A solution consisting of equal parts of glucose and dextrin was used. The limit of assimilability was determined in five animals, the doses which just resulted in glycosuria ranging from 10 to 16 gm. per kilo, while eight animals ingested doses ranging from 12 to 16 gm. per kilo without sugar appearing in the urine.

Table VII shows the relative assimilability of glucose, dextrin, and the glucose-dextrin mixture (1:1) in the same animals.

Table VII shows that three of the seven animals had a tolerance for glucose equal to or greater than that for the glucose-dextrin mixture, while in four the reverse was true. The dextrin tolerance was high in all animals, and, in those cases determined, was greater than that for either pure glucose or the glucose-dextrin mixture. It appears, therefore, that dextrin

mixed with glucose in the proportion of 1:1 does not always increase the assimilability of the latter.

History of a Typical Animal.

Rabbit 4.—This animal was a large male weighing at the beginning of the experiments 2,480 gm. After the ingestion of his first dose of sugar, 6.5 gm. per kilo of sucrose, reducing sugar appeared in the urine. Seven and

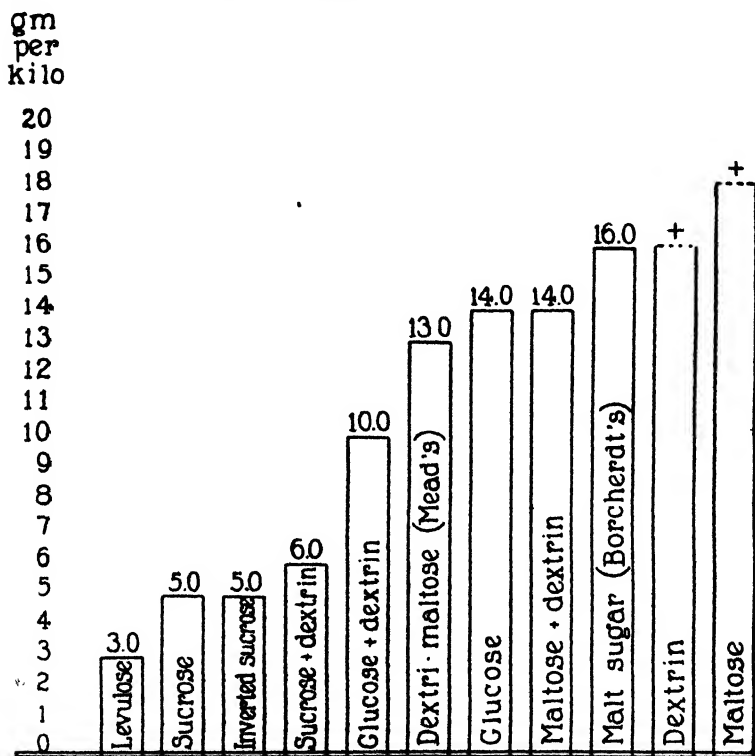


FIG. 1. Graphic representation of limits of assimilability of the various carbohydrates in Rabbit 4.

one-half months later, this animal received his fortieth dose of sugar. During this time he had maintained an approximately constant weight, and appeared to be in a normal condition at all times. The sucrose tolerance in this rabbit was found to be 5 gm. per kilo, reducing sugar *only* appearing in the urine. After he had received a large number of doses of various sugars

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during an interval of 3½ months, a second dose of sucrose, 5 gm. per kilo, was administered. As previously found, reducing sugar appeared in the urine. This same dose was repeated 2½ months later, and again reducing sugar was found in the urine. Apparently, repeated doses of sugars at frequent intervals had not affected the sucrose tolerance in this animal.

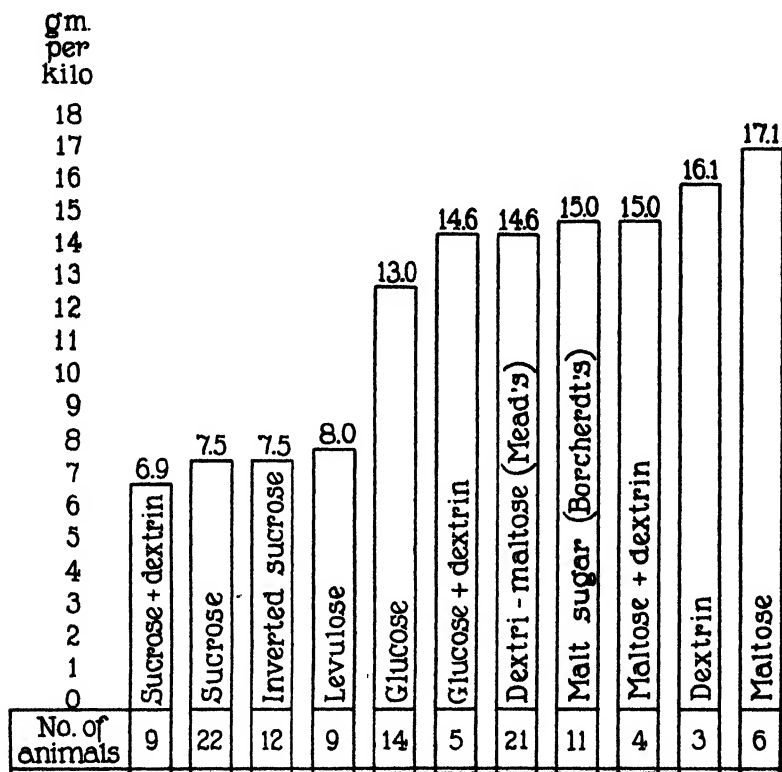


FIG. 2. Summary of observations on urine: graphic representation of the average limits of assimilability of the various carbohydrates.

Compared with other rabbits, No. 4 had a relatively low sucrose tolerance (5 gm. per kilo) and a fairly high dextrin tolerance (16 gm. per kilo). When the two carbohydrates were mixed in the proportion of 1:1, the assimilation limit of the mixture was found to be only 6 gm. per kilo. The assimilation limit of inverted sugar in this animal was the same as that of sucrose, and since reducing sugar invariably appeared in the urine after sucrose ingestion, it is probable that the latter was inverted in the intestinal tract before absorption (Figs. 1 and 2).

From Table VIII it appears that, for the carbohydrates studied, tolerance in rabbits occurred in the following order of increasing assimilability: (1) sucrose; (2) levulose; (3) glucose; (4) maltose and dextrin.

While from the table maltose appears to be more assimilable than dextrin, the reverse is probably true, since the tolerance for the latter was so great that the *limit* of assimilability could not be determined except in a few cases.

TABLE VIII.
Summary of Observations.

Carbohydrates.	Rabbits to which carbohydrates were fed.		Rabbits in which limits of assimilability were determined.		
	Total No.	No. developing diarrhea.	Total No.	Average tolerance.	No. developing diarrhea.
				gm.	
Glucose.....	18	6	14	13.0	2
Levulose	17	1	9	8.0	0
Inverted sucrose.....	17	2	12	7.5	2
Sucrose.....	58	8	22	7.5	1
Maltose	14	1	6	17.1	0
Lactose	4	0	0		
Dextrin.	25	0	3	16.1	0
Dextri-maltose.....	39	6	21	14.6	1
Malt sugar... ..	27	5	11	15.0	0
Maltose (50 per cent)	5	0	4	15.0	0
Dextrin (50 " ")					
Sucrose (50 " ")					
Dextrin (50 " ")					
Glucose (50 " ")	14	2	5	14.6	0
Dextrin (50 " ")					

Maltose-dextrin and glucose-dextrin mixtures were highly assimilable, while the sucrose-dextrin mixture was the least assimilable of all the carbohydrates tested.

The limit of assimilability of the maltose-dextrin mixtures averaged, on the whole, less than that of pure maltose or pure dextrin.

Taking all the animals tested into account, the glucose-dextrin mixture was slightly more assimilable than pure glucose and less

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assimilable than pure dextrin, but in five animals which received doses of all three preparations the average tolerance for the glucose-dextrin mixture was no greater than that for pure glucose and less than that for pure dextrin.

Diarrhea rarely occurred unless the dose of carbohydrate exceeded the assimilation limit.

STUDIES ON CARBOHYDRATE METABOLISM IN RABBITS.

II. EFFECT OF CARBOHYDRATE FEEDING ON BLOOD SUGAR.*

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(Received for publication, June 23, 1920.)

In a previous communication by Mendel and Jones¹ feeding experiments with the various carbohydrates ordinarily used in infant feeding were reported. As determined in those experiments, carbohydrate tolerance in rabbits occurred in the following order of increasing assimilability: sucrose, levulose, glucose, dextri-maltose, Borchardt's malt sugar, maltose, and dextrin. Glucose, maltose, and dextrin were highly assimilable, but when dextrin was added to glucose and maltose in the proportion of 1:1, the mixtures were, in some cases, less assimilable than the pure sugars. A mixture of sucrose and dextrin in equal proportions was the least readily assimilable of all the carbohydrates tested. With these results in mind, two questions arose: first, What relation exists between the sugar in the urine and that in the blood? and second, To what are differences in utilization due?

In order to determine the relation between sugar in the urine and that in the blood, a series of experiments was planned to study the composition of these fluids after the ingestion of com-

* The data in this paper were taken from the dissertation presented by Martha R. Jones for the degree of Doctor of Philosophy, Yale University, 1920. Part of the expense of the investigation was defrayed by a grant from the Russell H. Chittenden Research Fund for Physiological Chemistry.

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¹ Mendel, L. B., and Jones, M. R., *J. Biol. Chem.*, 1920, xliii, 491.

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parable doses of the various carbohydrates under investigation. Since the limit of assimilability of sucrose is relatively low, comparisons were made on the basis of sucrose tolerance.

Methods Employed.

MacLean's² micro method requiring 0.2 cc. of blood was used for the determination of the blood sugar. The accuracy of the method was tested by adding known quantities of glucose to blood samples which had previously been analyzed and determining the total amount of sugar present. Most satisfactory results were obtained. As in all micro methods, extreme care had to be exercised, and all pipettes and flasks kept scrupulously clean. After the addition of the colloidal iron to the coagulated blood mixture the flask should be shaken vigorously for at least 1 minute, a point which is not emphasized by MacLean, but was found to be quite essential. A sort of emulsion is formed which filters quite slowly, but much better duplicates were obtained when this precaution was taken. Two sets of flasks were used, one exclusively for precipitating the proteins and the other for the reduction of the copper solution. The flasks in which the proteins were precipitated (colloidal iron being used) had to be scrubbed after each test, as the iron adhered very closely to the glass and it was found impossible to remove it completely in any other way. One disadvantage of the method is that it requires about 40 minutes for each determination, making frequent tests impossible when observations are being made on both blood and urine. A great advantage is that the method lends itself very well to the determination of sucrose in the blood. An aliquot of the filtrate from the coagulated blood mixture was made acid with ten drops of a concentrated HCl solution and gently boiled for 10 minutes. The flask was stoppered and a long glass tube inserted to prevent evaporation. At the end of 10 minutes the flask was plunged into cold water and the solution titrated with NaOH of such a strength that ten drops exactly neutralized the ten drops of HCl used. One drop of phenolphthalein was used as indicator. Since a small amount of water was lost by evaporation the twenty drops of HCl and NaOH added did not materially change the volume of solution. From this point the procedure was exactly the same as that described by MacLean. The method was tested by adding known quantities of sucrose to the blood filtrate and testing before and after inversion. Satisfactory results were obtained.

Blood samples were taken immediately before and 1 hour after the ingestion of the sugar solution, while urine was collected before and 2 hours after the administration of the sugar. In a few cases the blood was collected at hourly intervals for 3 hours. As reported by numerous investigators, the sugar content invariably reached its maximum within the 1st hour. Each rabbit was weighed and its normal urine collected and tested

² MacLean, H., *Biochem. J.*, 1919, xiii, 135.

as previously described. It was then fastened on the animal board and a small incision made in the marginal ear vein, from which the blood was allowed to flow into a small weighing bottle containing a few grains of powdered potassium oxalate. At times some difficulty was experienced in obtaining a good flow of blood, but this was overcome by warming the ear with a lighted electric bulb. As only 0.2 cc. of blood was used for each test, a very small amount was collected. Since blood contains a glycolytic ferment, the sugar tests, in duplicate, were started immediately after the blood was drawn. While the rabbit was still fastened on the board the sugar solution was administered. The animal was then returned to its cage and 1 hour later a second blood sample was taken and tested as above. 2 hours after the ingestion of the sugar the urine was collected and tested for sugar with Benedict's reagent.

The Normal Blood Sugar.

The concentration of sugar in the blood was determined in sixteen normal rabbits, the average being 0.086 per cent. The highest blood sugar content exhibited by any animal was 0.116 per cent, while two had a sugar concentration of only 0.068 per cent. The normal blood sugar of each animal was tested at intervals until three or more determinations had been made, but the variations were found to be negligible and always within the limits of experimental error.

For the rabbit, the following data regarding normal blood sugar values have been collected by Allen.³

Investigator.	Blood sugar.
	<i>per cent</i>
Schenck.....	0.12
Lewandowski.....	0.09
Andersson and Erlandsen.....	0.12 to 0.13
Rose.....	0.15 (Maximum, never up to 0.2.)
Nishi.....	0.075 to 0.165
Lytthgens and Sandgren.....	0.222
Wacker.....	0.21 to 0.27
Schirokauer.....	0.10 to 0.11

Allen considers the great differences in blood sugar values probably due to the fact that the rabbit is an animal subject to

³ Allen, F. M., *Studies concerning glycosuria and diabetes*, Cambridge, 1913.

emotional and traumatic hyperglycemia to an unusual degree, and that the lowest figures are the most trustworthy.

A striking demonstration of extreme emotional hyperglycemia was obtained in one of our own animals. The rabbit was a young male in excellent physical condition but was unaccustomed to close confinement or handling. When placed on the animal board he showed great excitement and his blood sugar had a concentration of 0.187 per cent. After the ingestion of 8 gm. per kilo of glucose the blood sugar content increased to 0.264 per cent, the highest ever obtained, accompanied by extreme glycosuria. A month later this animal's blood sugar was again tested. He still showed some excitement when handled but the blood sugar content was only 0.138 per cent. Recent reports in which improved methods for the determination of blood sugar have been employed tend to show that the normal blood sugar content of the rabbit is much lower than originally thought, in fact, is very near the concentration in man. Allen asserts that it is not improbable that all or most mammals may be found to have a rather constant blood sugar content.

The Relation between Blood Sugar and Urine Sugar after the Ingestion of Certain Carbohydrates.

Glucose.—Eight rabbits received one or more doses of glucose. The relation between the sugar in the blood and that in the urine after the ingestion of glucose is shown in Table I.

Table I shows that hyperglycemia results after the ingestion of glucose, and that the degree, in the same animal, is proportional to the quantity ingested. Only after the concentration of the sugar in the blood reaches a certain degree does it escape into the urine. According to Hamman and Hirschman⁴ the blood sugar in man rises rapidly but seldom exceeds 0.15 per cent after the ingestion of glucose. It falls somewhat more slowly to the original level, the whole reaction taking place in less than 2 hours. "If the blood sugar passes 0.18 per cent sugar usually appears in the urine, but sometimes appears at a lower level and at other times fails to appear even though 0.2 per cent is exceeded."

⁴ Hamman, L., and Hirschman, I. I., *Johns Hopkins Hosp. Bull.*, 1919, xxx, 306.

The results of the above experiments on rabbits confirm the statement of Hamman and Hirschman. Sugar appeared in the urine only once when the blood sugar content was as low as 0.137 per cent. Five animals had sugar in the urine when the blood sugar concentration was 0.18 per cent or more. In six out of seven cases the doses of glucose ranging from 6 to 9 gm. per kilo produced a hyperglycemia of 0.138 to 0.168 per cent without glucosuria.

Sucrose.—Thirteen rabbits received doses of sucrose ranging from 6 to 8 gm. per kilo. The blood and urine were tested for reducing substances before the ingestion of the sugar, and for

TABLE I.

Animal No.	Glucose per kilo.	Blood sugar.		Sugar in urine.
		Normal.	1 hr after sugar.	
	gm.	per cent	per cent	
109	9.0	0.087	0.144	—
109	12.0	0.087	0.186	Trace.
110	6.0	0.09	0.14	—
110	8.0	0.09	0.212	+
111	6.0	0.116	0.168	—
111	8.0	0.116	0.25	++
112	7.5	0.07	0.142	—
113	7.0	0.085	0.137	+
114	7.0	0.08	0.138	—
115	7.0	0.084	0.181	++
116	7.0	0.09	0.165	—
116	10.0	0.09	0.25	++

both reducing substances and sucrose after the ingestion. In twelve of the thirteen rabbits sucrose, as such, appeared in the urine, while in one the assimilation limit was not reached. Five rabbits showed a more or less marked *decrease* in reducing sugar in the blood. After inversion, the *total* sugar content was approximately normal, indicating the presence of sucrose. These rabbits also exhibited sucrosuria to a marked degree. Eight animals showed the same or an increase in reducing substances in the blood after the ingestion of sucrose. In three of these cases, sucrose, as such, was present; in one, no appreciable increase in reduction was noted after inversion; and in four, the presence of sucrose was not determined.

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Rabbit 114, which had no increase in blood sugar but marked sucrosuria after the ingestion of 7 gm. per kilo of sucrose, was given a second dose of the sugar (6 gm. per kilo) 5 days after the first. The blood sugar content increased from 0.07 to 0.121 per cent during the 1st hour, only reducing sugar being present. The urine test showed marked reduction, with no increase after inversion. One of two possibilities may have occurred. Either the sucrose was completely inverted in the intestines before absorption, or, if a small portion of the unchanged sugar found its way into the blood stream, an enzyme, evoked by the previous dose of sugar may have inverted it. Neither the dog nor the rabbit has sucrase in its normal serum.³ Weinland⁵ was able by repeated subcutaneous injections of sucrose in dogs to produce an invertin in their serum. In the present investigation the pres-

TABLE II.

Animal No.	Sucrose per kilo.	Blood sugar.			Urine sugar.	
		Normal.	1 hr. after sugar.	After inversion	Reducing.	Sucrose.
	<i>gm.</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>		
109	7 0	0.086	0 065	(?)	—	—
110	6 0	0 085	0 05	0 081	Trace.	+
111	6.0	0.116	0 055	0 112	+	++
112	7 5	0 07	0 052	0 072	—	+
114	7 0	0 087	0.075	0 089	Trace.	+++

ence of an amylase in rabbit urine after the ingestion of sucrose has been repeatedly demonstrated. No tests for sucrase, however, were made, but it seems reasonable to assume that it might have been present. Rabbit 114 also received 7 gm. per kilo of glucose. The blood sugar content rose to 0.138 per cent without glycosuria. The fact that glycosuria resulted after sucrose ingestion when the concentration of sugar in the blood was only 0.121 per cent and did not result after glucose ingestion when the blood sugar content was 0.138 per cent indicates a relatively low renal threshold for invert sugar.

Table II shows the relation of glycemia to glycosuria in those animals which exhibited a lowered content of reducing sugar in the blood after the ingestion of sucrose.

⁵ Weinland, E., *Z. Biol.*, 1906, xlvii, 279.

Table III shows the relation between glycemia and glycosuria in those animals which exhibited an increase in reducing sugar in the blood after the ingestion of sucrose.

Rabbits 103, 107, and 108 showed marked sucrosuria with more or less glucosuria. The sucrose concentration in the blood was also high, while the concentration of reducing sugar was relatively low.

From Tables II to III two distinct phenomena are apparent: first, *hypoglycemia* with *normal total blood sugar*, accompanied by sucrosuria; second, a *relatively low glycemia* with high *total blood sugar* accompanied by both glycosuria and sucrosuria.

TABLE III.

Animal No	Sucrose per kilo.	Blood sugar.				Urine sugar.	
		Normal.	1 hr. after sugar.	2 hrs. after sugar.	After inversion.	Before inversion.	After inversion.
	gm.	per cent	per cent	per cent	per cent		
101	7 5	0.08		0 08		+	++
102	7 0	0 068		0 104		+	++
103	6.0	0 084		0 116	0 187	+	++
104	6 0	0 08		0 08		—	—
107	6 0	0 081	0.137		0 166	+	++
108	7.0	0 067	0 103		0 147	Trace.	++
113	7 0	0 081	0 144		0 144	++	++
115	7 0	0 07	0 125			—	+

Dextri-Maltose.—The blood sugar content was determined in twelve animals after the ingestion of one or more doses of dextri-maltose (Mead's). The relation between the sugar in the blood and that in the urine in these animals is given in Table IV.

Table IV presents, in general, two distinct blood pictures: first, large doses of sugar resulting in relatively low hyperglycemia accompanied by glycosuria; second, large doses of sugar with little or no increase in blood sugar and no sugar in the urine. In all cases except two (Rabbits 104 and 112) an increase in dose resulted in an increase in blood sugar. Rabbits 105, 108, 111, and 116 ingested 14, 7, 6, and 10 gm. per kilo, respectively, without an appreciable increase in blood sugar or glycosuria resulting. Rabbits 103, 104, and 116 received 14 gm. per kilo each with only a slight increase in blood sugar although there was a small

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amount of sugar in the urine. It is possible that the sugar was so slowly absorbed in these cases that the maximum blood sugar value was not attained during the 1st hour.

Dextrin.—Owing to our inability to obtain a sufficient amount of purified dextrin, only three doses were given. Rabbits 109, 112, and 113 received 12, 10, and 7 gm. per kilo, respectively, of a so called chemically pure dextrin, but a different product from that used in previous experiments. The highest blood sugar value attained was 0.145 per cent. Glycosuria resulted in two cases.

TABLE IV.

Animal No.	Dextri-maltose per kilo.	Blood sugar.		Sugar in urine.
		Normal.	1 hr. after sugar.	
	gm.	per cent	per cent	
101	7.5	(?)	0.093	—
103	14.0	0.09	0.116	Trace.
104	14.0	0.087	0.106	"
104	12.0	0.087	0.13	—
105	14.0	0.112	0.121	—
106	15.0	0.085	0.202	++
106	10.0	0.085	0.108	—
107	10.0	0.082	0.162	—
107	6.0	0.082	0.142	—
108	10.0	0.062	0.15	—
108	7.0	0.062	0.075	—
110	6.0	0.081	0.103	+
111	6.0	0.116	0.127	—
112	10.0	0.07	0.125	—
112	7.5	0.07	0.121	—
114	10.0	0.087	0.105	—
116	14.0	0.09	0.133	+
116	10.0	0.09	0.091	—

Comparing the blood sugar values after the ingestion of glucose and dextri-maltose it appears that comparable and even larger doses of the latter result in relatively lower concentrations of blood sugar (Table V). In addition to the above carbohydrates, Rabbit 109 received 12 gm. per kilo of pure maltose, the blood sugar content rising to 0.16 per cent 1 hour after the ingestion of the sugar. It seems that the glucose threshold value in this animal was approximately 0.144 per cent, since a trace of sugar

appeared in the urine when the blood sugar attained that concentration after ingestion of 9 gm. per kilo of glucose, and positive tests resulted when glycemia increased to 0.145, 0.16, and 0.186 per cent after the ingestion of 12 gm. per kilo of dextrin, maltose, and glucose respectively. These relative values lend credence to the theory that polysaccharides are more slowly digested and

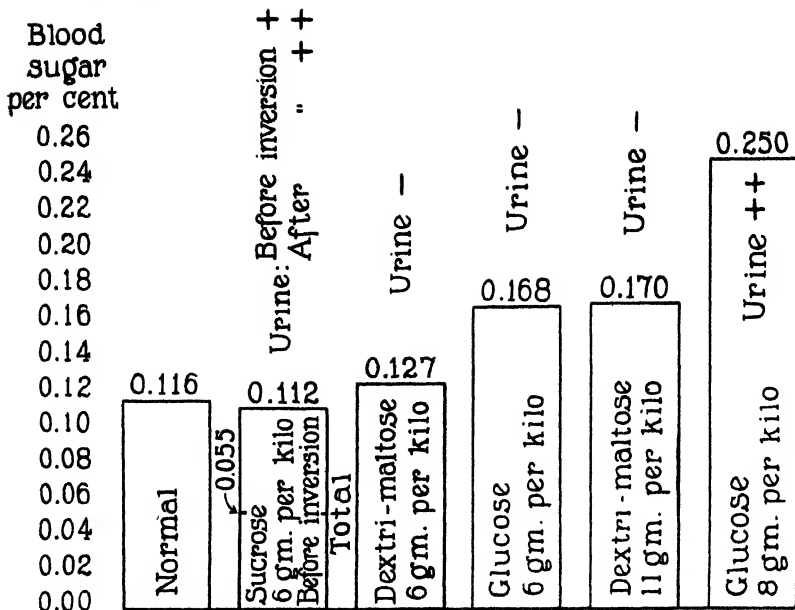
TABLE V.

Comparison of Blood Sugar Values in Selected Animals.

Animal No.	Normal blood sugar.	Sucrose.			Glucose.		Dextri-maltose.		Dextrin.	
		Amount ingested.	Blood sugar before inversion.	Blood sugar after inversion.	Amount ingested.	Blood sugar.	Amount ingested.	Blood sugar.	Amount ingested.	Blood sugar.
	per cent	gm.	per cent	per cent	gm.	per cent	gm.	per cent	gm.	per cent
109	0.086	7 0	0 065		9	0.144	12 0	0.137	12	0.145
					12	0 186				
110	0 085	6 0	0 05	0.081	6	0.14	6 0	0.103		
					8	0.212	10.0	0.140		
111	0 116	6.0	0.055	0 112	6	0.168	6.0	0.127		
					8	0.25	11.0	0.17		
112	0.07	7 5	0 052	0 072	7 5	0.142	7.5	0.121	10	0.143
							10.0	0.125		
113	0.081	7.0	0.144	0.144	7	0.138			7	0.137
114	0.087	6.0	0.121	0.131	7	0.138	10.0	0.105		
		7.0	0.075	0.089						
116	0.09				7	0.165	10.0	0.091		
					10	0.25	14.0	0.133		

absorbed than monosaccharides, and that upon the rate of absorption depends the ability of the liver and tissues to utilize the excess. Two rabbits (Nos. 112 and 109) showed no higher blood sugar after the ingestion of 10 and 12 gm. per kilo of dextrin, respectively, than after the ingestion of 7.5 and 9 gm. of glucose, which indicates slower absorption of the former. Rabbit 113 had a blood sugar content of 0.137 per cent accompanied by

Rabbit 111



Rabbit 110

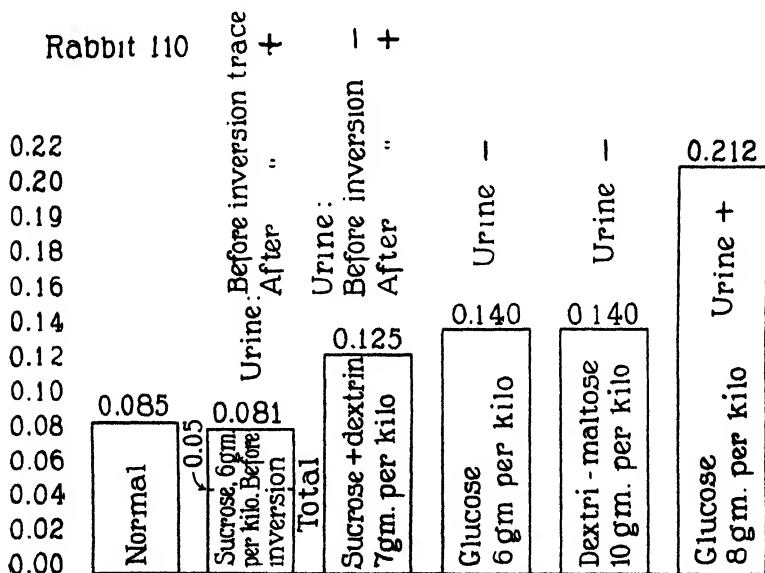


FIG. 1. Graphic representation of blood sugar content of certain individual animals.

glycosuria after the ingestion of glucose, while a comparable dose of dextrin resulted in the same concentration of sugar in the blood but without glycosuria. This also can be explained on the ground of more rapid initial absorption of glucose, its maximum value probably having been attained before the expiration of the hour.

In the few experiments in which two or more doses of glucose were given to the same animal, the sugar concentration in the blood invariably increased with the size of the dose. Sucrose in the same dosage as glucose, with one exception, resulted in no increase in total blood sugar, the reducing sugar being below normal (Fig. 1).

DISCUSSION.

When sugar is ingested orally its passage into the urine may be prevented in three ways: first, by the liver which converts it into glycogen; second, by the tissues which metabolize it; and third, by the kidneys which fail to excrete it unless the concentration in the blood exceeds a certain level.

Bernard established the theory that the kidneys were essentially like a dam to a reservoir. The blood sugar could stand at a certain level without loss, but if this level for any reason should be raised the excess flowed over the dam until the original height was restored. This conception is still common in the literature, but recent investigations show that in the normal organism the power to utilize sugar is practically unlimited. An increase in dose means an increase in utilization, and the quantity of sugar excreted is invariably an exceedingly small proportion of the sugar ingested. In this respect the normal organism differs from that of the total diabetic in whom the kidneys regulate the height of the blood sugar by allowing the excess above a certain level to escape quantitatively in the urine.

In a recent paper by Hamburger⁶ observations on the permeability of the kidney to various sugars were reported. From these experiments it appears that the kidney is perfectly permeable to the three disaccharides as well as to fructose and levorotatory glucose. In perfusion liquids containing mixtures of

⁶ Hamburger, H. J., *Brit. Med. J.*, 1919, i, 267.

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glucose and levulose, also glucose and lactose, both the levulose and lactose passed through the glomeruli quantitatively, while the retention of glucose was not altered. According to Hamburger: "The two sugars are simply separated from each other as through a filter" Apparently, the glomerular epithelium has the power of retaining free glucose and distinguishing it from other sugars, a power which is governed by the influence of the chemical composition of the perfusion liquid upon the glomerular membrane.

On the basis of this hypothesis most of the phenomena observed in the present research can be interpreted. Since the kidney appears to be perfectly permeable to sucrose, levulose, and maltose, once they enter the blood stream they are excreted. Since, however, a maltase occurs in the blood, any maltose which escapes into the circulation is rapidly converted into glucose and none escapes into the urine until the concentration in the blood exceeds a certain limit. On the other hand, sucrose entering the circulation, as such, is rapidly excreted, since the normal blood serum contains no sucrase. The addition of dextrin to sucrose facilitated the passage of the latter into the blood stream, and hence even relatively small doses gave rise to glycosuria. The fact that sucrose was nearly always present in the urine after the ingestion of the mixture makes this seem more probable. That levulose is more assimilable than sucrose can be explained on the ground that less of it enters the systemic circulation, owing to its ready conversion into glycogen by the liver. This assumption is supported by the fact that after parenteral injections of levulose relatively small quantities are utilized by the tissues. Since polysaccharides have to undergo hydrolysis in the intestinal tract before absorption, it is reasonable to assume that absorption takes place more slowly after the ingestion of starch and dextrin than after the ingestion of glucose and maltose. Why a glucose-dextrin mixture in some cases had no greater limit of assimilability than pure glucose we are unable to say, unless in the presence of dextrin the preformed glucose undergoes more rapid absorption.

Kidney Function Test.

Since the kidney is an important factor in preventing the escape of sugar into the urine, it seemed desirable to test what effect, if any, large doses of sugar have upon kidney function, and for this purpose the phenolsulfonephthalein test was employed.

0.5 cc. of a phenolsulfonephthalein solution containing 3 mg. of the dye was diluted to 1 cc. with distilled water and injected subcutaneously into the rabbit immediately after the ingestion of 50 cc. of distilled water or sugar solution. The urine was collected in some cases after 2 hours and in others after 3 hours. Two or three drops of concentrated NaOH solution were added to the urine to develop the color and the volume was made up to 500 cc. with distilled water. The percentage of the dye in the urine was determined by matching the color in a Hellige colorimeter against a standard solution containing 3 mg. of phenolsulfonephthalein, 15 cc. of normal urine, and two or three drops of concentrated NaOH made up to a volume of 500 cc. Solutions of sucrose, maltose, dextrin, dextri-maltose, maltose + dextrin, and glucose + dextrin were fed, the excretion of the dye being well within the normal limits in all cases both in the 2 and 3 hour periods. Apparently, large doses of these carbohydrates have no appreciable effect upon kidney function as determined by this test.

SUMMARY.

Comparable doses of carbohydrates gave rise to hyperglycemia in the following order of increasing blood sugar values: dextrin, dextri-maltose, and glucose.

Sucrose ingested in doses sufficient to cause glycosuria presented three distinct phenomena: (1) *hypoglycemia* with normal total blood sugar content accompanied by sucrosuria; (2) a relatively low glycemia with high total blood sugar value accompanied by both glycosuria and sucrosuria; (3) *hyperglycemia* accompanied by glycosuria.

In the few determinations made, maximum blood sugar values were attained 1 hour after the ingestion of glucose and dextri-maltose, an increase in dose resulting, in general, in an increase in blood sugar content.

STUDIES ON PROTEINOGENOUS AMINES.

VI. THE PREPARATION OF HISTIDINE FROM BLOOD CORPUSCLE PASTE.

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Since Fränkel¹ published his method for the preparation of histidine, small quantities of this substance have been obtainable without difficulty. The details given by Fränkel are rather incomplete. Most laboratories have found it necessary, therefore, to supply the exact details in order that their students could prepare this amino-acid successfully. One very good unpublished modification with which we are familiar is that devised by Dr. F. C. Koch of the Department of Physiological Chemistry at the University of Chicago. Jones,² who was formerly one of Koch's students, has recently published a method for preparing histidine that is essentially that of Koch.

Anyone who has prepared histidine repeatedly by one of these processes cannot fail to have been struck by the uncertainty of the results. The yield of histidine dichloride may vary between the wide limits of 10 to 25 gm. from 2 liters of the same corpuscle paste. Frequently the presence of impurities in the crude histidine dichloride makes it difficult to obtain a good yield of the pure substance. The most serious causes of difficulty seem to be the following.

1. The precipitation of humin and ferric hydroxide by means of sodium carbonate is very unreliable. Even an experienced chemist may waste considerable time before the correct condition for complete precipitation is obtained. By using lime in place of sodium carbonate this difficulty can be removed entirely.

¹ Fränkel, S., *Monatsh. Chem.*, 1903, xxiv, 230.

² Jones, H. M., *J. Biol. Chem.*, 1918, xxxiii, 429.

2. The mercury salt of histidine has usually been prepared by adding sodium carbonate and mercuric chloride alternately until precipitation has ceased. We have found that *the precipitation is always incomplete unless an excess of mercuric chloride is present from the start*; that it is necessary to use far more mercuric chloride than has usually been employed; and that by using exact weights of mercuric chloride and sodium carbonate a uniformly complete precipitation can always be obtained.

3. The final purification of the histidine dichloride by the previously described methods has been subject to considerable loss both of time and material. By recrystallizing the crude product from aqueous alcohol under exactly defined conditions, a very good yield of a perfectly pure final product is obtained. The process to be described has given an average yield of 15 gm. of pure histidine dichloride from 500 cc. of blood corpuscle paste, which is about four times the quantity that has usually been obtained.

EXPERIMENTAL.

1. *Hydrolysis*.—Fresh blood corpuscle paste,³ 500 cc., is mixed with 1,000 cc. of 37 per cent hydrochloric acid in a weighed 3,000 cc. long necked, round bottomed Pyrex flask and hydrolyzed by boiling, under a reflux condenser, for 30 hours over an electrically heated asbestos bath.

2. *Removal of the Hydrochloric Acid*.—The hydrochloric acid is removed by distillation *in vacuo* at 60° from the same flask. The residue is finally dried at 100° for 2 hours to remove the water and acid as completely as possible. The flask is weighed and the weight of the residue—usually about 350 gm.—is obtained by difference. This weight is very important because the quantities of mercuric chloride and sodium carbonate used later in the preparation depend upon it. This will be referred to later as Residue 2.

3. *Removal of Ammonia*.—Residue 2 is dissolved in 1,000 cc. of water. The solution is treated with commercial finishing lime until the reddish brown precipitate formed at first assumes a homogeneous clay color due to the presence of undissolved lime.

³ The blood corpuscle paste was obtained from Armour and Company, Chicago, Ill.

The saturation with lime is necessary to insure a complete precipitation of the ferric hydroxide and humin. The mixture is treated with 500 cc. of 95 per cent alcohol and subjected to a distillation *in vacuo* at 40° until about 800 cc. of distillate have been collected. This removes the ammonia completely.

4. *Removal of Humin and Ferric Hydroxide.*—The mixture is filtered, on a 6 inch Buchner funnel, from humin, ferric hydroxide, and excess lime, the precipitate being carefully washed with a large volume—2,000 cc.—of a hot saturated aqueous solution of lime. The clear amber-colored liquid, which contains all the amino-acids as lime salts, is always free from iron when enough lime has been added.

5. *Isolation of Tyrosine and Leucine.*—The alkaline filtrate obtained under Section 4 is diluted to 4,000 cc., heated on the water bath, and treated with 350 gm.⁴ of solid anhydrous sodium carbonate. The resulting mixture is agitated until all the sodium carbonate has passed into solution. This precipitates the calcium as calcium carbonate. The mixture is filtered promptly on a 6 inch Buchner funnel and the precipitate is washed with 1,000 cc. of hot water. The filtrate, which should be free from calcium, is transferred to a 6 liter flask, cooled under the tap, and treated with 37 per cent hydrochloric acid *until the liquid reacts neutral to litmus paper*. Glacial acetic acid is then added until effervescence ceases. The solution is subjected to a distillation *in vacuo* at 50–60° until its volume has been reduced to about 800 cc. Sodium chloride crystallizes out toward the end of the distillation together with small quantities of tyrosine and leucine. The mixture is placed in the ice chest for 4 days which separates the tyrosine almost completely, and considerable leucine. It is then filtered on a 5 inch Buchner funnel, the precipitate being washed with 200 cc. of ice-cooled water.

The precipitate contains about 50 gm. of leucine and 1.5 gm. of tyrosine together with a large quantity of sodium chloride. The

⁴ The weights of mercuric chloride and sodium carbonate given here are correct only when the weight of Residue 2 (p. 522) is 350 gm. The weight of this residue is, of course, dependent upon the quality of the blood corpuscle paste. In case Residue 2 does not weigh approximately 350 gm., the quantities of HgCl_2 and Na_2CO_3 to be used can be obtained by proportion.

separation of the leucine from the tyrosine and the further purification of these two amino-acids can be most easily accomplished by the method of Habermann and Ehrenfeld.⁵

The filtrate, which contains the histidine, is diluted to exactly 2,000 cc. It will be referred to as Filtrate 5.

6. *Precipitation of the Mercury Compound of Histidine.*—The filtrate from the tyrosine and leucine—Filtrate 5, volume 2,000 cc.—is divided into four equal parts.⁶ Each 500 cc. portion is transferred to a 6,000 cc. flask and diluted with 1,500 cc. of water. The further discussion will be limited to *one* of these portions. The other three portions are treated in a manner identical to that which will be described.

Solid mercuric chloride—350 gm.,⁷ *four times the weight of Residue 2 which is present in this portion*—is added to the acid liquid. The mixture is heated on the water bath until the sublimate has passed into solution. A small quantity of a gray to brown flocculent precipitate is always present. This can be more advantageously removed later. The liquid is cooled. The mercury salt remains in solution. A solution of sodium carbonate, containing 70 gm.⁷ of anhydrous salt dissolved in 3,000 cc. of water, is carefully added to the above liquid. This precipitates the mercury salt of histidine in the form of a flocculent white solid that settles readily leaving a clear supernatant liquid. A test portion of this liquid should give no immediate precipitate when it is treated with a sodium carbonate solution. The clear supernatant liquid is removed as completely as possible by means of a glass siphon. Distilled water—about 4,000 cc.—is poured into the flask, the mixture thoroughly agitated, and the precipitate allowed to settle. The supernatant liquid is siphoned off as before. The mercury salt is washed seven times in this manner.

7. *Isolation and Purification of Histidine Dichloride.*—The four batches of mercury salt obtained under Section 6 are combined in a 6 liter flask. Hydrochloric acid—37 per cent—is then added until

⁵ Habermann, J., and Ehrenfeld, K., *Z. physiol. Chem.*, 1902-03. xxxvii. 18.

⁶ This division of material was necessary because of the limited size of the laboratory glassware. Then too, the final volume of the entire portion would be 20 liters which is too large a quantity to be handled easily.

⁷ In general use 20 gm. of anhydrous sodium carbonate for every 100 gm. of mercuric chloride.

all the white solid has passed into solution. A small quantity of a gray to brown flocculent precipitate is always left that will not dissolve in hydrochloric acid. The mixture is filtered through a large folded filter paper into a 2 gallon bottle. The pale yellow filtrate is saturated with hydrogen sulfide under pressure which removes the mercury completely. The resulting mixture is filtered on a 6 inch Buchner funnel, and the clear *colorless* filtrate is subjected to a vacuum distillation at 60° in a weighed flask. The resulting pale yellow, exceedingly stiff gum is freed from water and hydrochloric acid as completely as possible by heating *in vacuo* at 80° for 2 hours. The gum so obtained—60 to 65 gm.—is dissolved in 60 cc. of 37 per cent HCl by heating on the water bath. The resulting pale brown solution should be free from crystalline matter⁸ and will usually remain clear for days if it is kept at room temperature. A few crystals of histidine dichloride are added and the sides of the vessel scratched with a glass rod. The crystallization of histidine dichloride is immediate and so copious that the mass sets to the consistency of paste in the course of 10 minutes. The mixture is placed in an ice bath where it is kept for 2 days to complete the precipitation of histidine dichloride; it is then filtered on a 3 inch Buchner funnel.⁹ The white granular powder is washed first with about 50 cc. of cold 37 per cent HCl and then with a cold mixture containing 20 cc. of 37 per cent HCl and 20 cc. of alcohol. After drying at 100° for 10 hours, this solid, which is nearly pure histidine dichloride, weighs from 17 to 19 gm. The following concrete example illustrates the further purification of this product.

Of the crude histidine dichloride, 30 gm. are dissolved in 20 cc. of hot water. Hot 95 per cent alcohol—200 cc.—is added to the above aqueous solution. The liquid is heated on the water bath until the alcohol boils,¹⁰ when it is filtered through a small

⁸ A slight crystalline residue is usually sodium chloride which indicates that the mercury compound of histidine was not washed sufficiently. This inorganic matter can be more advantageously removed later.

⁹ It is best to use two thicknesses of a fairly hard but not too retentive a grade of filter paper in this case.

¹⁰ When the entire process has been properly conducted, the aqueous alcoholic solution will contain no crystalline residue. If such a residue is present it consists of inorganic salts. These are then removed by the filtration that is carried out in any case to remove shreds of filter paper and bits of broken glass.

folded filter into a 300 cc. Pyrex flask. The clear, nearly colorless filtrate slowly deposits large colorless plates of histidine dichloride. To hasten the crystallization these first crystals are titrated with a glass rod. The mixture is allowed to crystallize for 24 hours in the ice chest after which it is filtered with suction on a platinum cone, the crystals being washed with 50 cc. of cold 95 per cent alcohol. The pure white product so obtained, after drying *in vacuo* over sulfuric acid for 48 hours, is 100 per cent pure histidine dichloride.¹¹ The first crop weighs from 21 to 22 gm. A second crop—about 6 gm.—of equally pure material can be obtained from the mother liquor from Crop 1 by repeating the above recrystallization with the same proportions of water and alcohol.

¹¹ For a typical analysis see Koessler, K. K., and Hanke, M. T., *J. Biol. Chem.*, 1919, xxxix, 502.

STUDIES ON PROTEINOGENOUS AMINES.

VII. THE QUANTITATIVE COLORIMETRIC ESTIMATION OF HISTIDINE IN PROTEIN AND PROTEIN-CONTAINING MATTER.

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INTRODUCTION.

The Relation of Imidazole Derivatives to Certain Biochemical Problems.

The discovery of the imidazole nucleus in histidine gave rise to considerable speculation as to the possible mode of formation of this heterocyclic ring in living matter. The first suggestion as to its mode of formation was obtained from the then well known discovery by Debus¹ that glyoxal condenses with ammonia and formaldehyde to give imidazole. Windaus and Knoop² proved in 1905 that methyl imidazole is formed when glucose is allowed to stand for some time in the presence of zinc ammonium hydroxide. The work of these authors leaves little doubt that the methyl imidazole is formed by a condensation of methyl glyoxal and formaldehyde with ammonia, the two aldehydes having been previously formed from the glucose by the action of the ammonia. It is hardly necessary to say that the above condensations, occurring as they do only in the presence of a high concentration of ammonia, can scarcely be claimed to approach the conditions as we find them in living matter. The synthesis of imidazole derivatives by protoplasm may, nevertheless, involve building stones similar to those employed in the laboratory.

¹ Debus, H., *Ann. Chem.*, 1858, cvii, 204.

² Windaus, A., and Knoop, F., *Ber. chem. Ges.*, 1905, xxxviii, 1166.

Although histidine seems to be more abundant, in living matter, than any other imidazole derivative, there are others that may prove to be quite as important. Among these we might mention carnosine (β -alanyl-histidine³); histamine⁴ (β -imidazolylethylamine), a substance that has recently attracted considerable attention because of its powerful physiological activity; the purines, that can be considered as condensation products of the imidazole with the pyrimidine ring; the hydantoin; the closely related glycoyamidines; and creatinine. The last three of the above compounds, although they do not contain a typical imidazole nucleus, have a nuclear cyclic structure like that of the imidazoles. It is possible that a genetic relation exists between all these imidazoles; but this problem as well as the fate of the imidazoles in the animal organism, their relation to the secretagogues and the physiological action of organ extracts, the rôle they play in the diazo reaction of the urine, and many other related questions, could not be successfully approached as long as we were not in possession of an exact, simple, and rapid method for the estimation of imidazole derivatives.

The Method in Brief.

Histidine has been determined in the past by the original method of Kossel and Kutscher,⁵ by one of the numerous modifications of this method,⁶ and by the group method of Van Slyke.⁷ The present method, although it may be no more accurate than the best of those referred to above, has the advantages of being simple, rapid, and direct. The principles involved can be summarized briefly as follows:

³ Baumann, L., and Ingvaldsen, T., *J. Biol. Chem.*, 1918, xxxv, 263.

⁴ See Koessler, K. K., and Hanke, M. T., *J. Biol. Chem.*, 1919, xxxix, 539, for a discussion of previous work on histamine; and Hanke, M. T., and Koessler, K. K., *J. Biol. Chem.*, 1920, xliii, 543, for a method of estimation of this substance in complex mixtures.

⁵ Kossel, A., and Kutscher, F., *Z. physiol. Chem.*, 1901, xxxi, 165.

⁶ Kossel, A., and Patten, A. J., *Z. physiol. Chem.*, 1903, xxxviii, 39. Steudel, H., *Z. physiol. Chem.*, 1903, xxxvii, 219. Kossel, A., and Pringle, H., *Z. physiol. Chem.*, 1906, xlix, 318. Osborne, T. B., Leavenworth, C. S., and Brautlecht, C. A., *Am. J. Physiol.*, 1908, xxiii, 180.

⁷ Van Slyke, D. D., *J. Biol. Chem.*, 1911-12, x, 15.

The material is hydrolyzed by boiling with hydrochloric acid. The acid and the volatile phenols, if such are present, are removed by distillation *in vacuo*, after which ammonia and humin are removed by treatment with lime. The material is then divided into two fractions by means of phosphotungstic acid. The phosphotungstate *precipitate* contains the *histidine* together with arginine, lysine, and cystine. Of these four amino-acids, histidine is the only one that gives an orange-red color with an alkaline solution of *p*-phenyldiazoniumsulfonate. Tyrosine, which is, to the best of our present knowledge, the only substance that is normally present in non-putrid, protein-containing matter that could interfere with the colorimetric estimation of histidine, is *not* precipitated by phosphotungstic acid from a dilute solution. The phosphotungstate precipitate is treated with water and sufficient 3 N NaOH to give a clear solution. Histidine is then estimated colorimetrically in this liquid, using the method previously described by us,⁶ which is a modification of the familiar qualitative Ehrlich diazo reaction.

Histamine and tyramine, both of which give a pink color with *p*-phenyldiazoniumsulfonate, are also precipitated by phosphotungstic acid. If present they would be estimated as histidine. These amines are, however, never present in non-putrid, protein-containing matter in sufficient quantity to have the slightest effect upon the results.

The method depends, therefore, not upon the actual isolation of histidine, which is time-consuming and subject to the possibility of considerable error, but upon the quantitative determination of the imidazole ring.

Detailed Description of the Method.

The general mode of procedure can be summarized in the following six steps.

1. *Hydrolysis*.—The protein—1 to 3 gm.—is mixed with 60 cc. of 20 per cent hydrochloric acid in a 400 cc. long necked, round bottomed flask and hydrolyzed by boiling for 28 hours over an electrically heated sand or asbestos bath.

2. *Removal of the Hydrochloric Acid and Volatile Phenols*.—The hydrochloric acid and the volatile phenols are removed by

⁶ Koessler, K. K., and Hanke, M. T., *J. Biol. Chem.*, 1919, xxxix, 497.

distillation *in vacuo* at 60° from the same flask. The residue is finally dried *in vacuo* at 80° for 1 hour to remove the last traces of the free hydrochloric acid.

3. *Removal of Ammonia*.—The residue is dissolved in 100 cc. of water and the solution treated with an excess of lime and 50 cc. of 95 per cent alcohol. The ammonia, alcohol, and some of the water are then removed by distillation *in vacuo* at 40° (again from the same flask).

4. *Removal of Humin*.—The mixture is filtered, on a Buchner funnel, from humin and excess lime, the precipitate being carefully washed with a large volume of *hot* water until the washings give a negative Pauly reaction.

5. *Preparation of the Phosphotungstates*.—The alkaline filtrate is acidified by adding a slight excess of hydrochloric acid. The resulting clear, amber-colored liquid is then evaporated to dryness on the water bath in a glass dish. The residue is transferred to a 300 cc. Pyrex Florence flask with a solution of 18 cc. of 37 per cent hydrochloric acid in enough water to give a total volume of 100 cc. The resulting solution is heated on the water bath. To it are then added 100 cc. of a hot 15 per cent aqueous solution of phosphotungstic acid. The resulting mixture is digested for $\frac{1}{2}$ hour on the water bath. It is then allowed to cool slowly to room temperature, after which it is placed in the ice chest for 48 hours⁹ and finally cooled in an ice bath for 24 hours. Phosphotungstates have usually been precipitated at room temperatures. Histidine phosphotungstate is far more soluble at 20° than it is at 0° (see experimental part). By conducting the precipitation at 0°, 0.00571 gm. of histidine remains in solution in 200 cc. of precipitation liquid; a definite quantity that can be accurately corrected for. This quantity will be referred to later as the *solubility correction blank*.

6. *The Colorimetric Determination of Histidine*.—The ice-cold mixture obtained under Section 5 is filtered with the aid of suction, two thicknesses of filter paper and a platinum cone being used in preference to the Buchner funnel process described by Van Slyke.⁷ The precipitate is washed freely with an ice-cold liquid containing 18 cc. of 37 per cent hydrochloric acid and 15 gm. of phosphotungstic acid in a total aqueous volume of

⁹ Up to this point the method is essentially that of Van Slyke.⁷

200 cc., the liquid having been previously saturated with histidine phosphotungstate. Since the wash liquid is already saturated with histidine phosphotungstate it can dissolve none of this substance from the precipitate. No correction, therefore, need be made for the solubility of the precipitate in the wash fluid.

The well washed precipitate finally obtained is transferred, with the paper, to a 1,000 cc. lipped beaker. Enough of a 3 N sodium hydroxide solution is then added to dissolve the precipitate, a large excess of alkali being carefully avoided. The mixture is filtered through a folded filter paper into a 1,000 cc. volumetric flask, and the beaker and filter pulp are thoroughly washed out with distilled water. The clear, pale yellow filtrate is finally diluted to 1,000 cc. This solution will be referred to later as the *test liquid*. The colorimetric determinations are performed on this liquid according to the method previously described by us.⁸ The sodium phosphotungstate, which is always present in this liquid, does not interfere with the color production.

The following results have been obtained by using this method.

Histidine Content.

	Colorimetric.	Other methods.
	<i>per cent</i>	<i>per cent</i>
Casein.	2.84 first determination.	2.09 Van Slyke, using the method of Osborne, Leavenworth, and Brautlecht with preliminary phosphotungstic acid precipitation at room temperature (Van Slyke, D.D., <i>J. Biol. Chem.</i> , 1913-14, xvi, 533).
		2.30 Van Slyke, direct precipitation with AgNO ₃ and baryta (Van Slyke, D.D., <i>J. Biol. Chem.</i> , 1913-14, xvi, 535).
	2.84 second determination.	3.37 Van Slyke by group method (Van Slyke, D.D., <i>J. Biol. Chem.</i> , 1913-14, xvi, 537).
		2.59 (Abderhalden, E., <i>Z. physiol. Chem.</i> , 1905, xlv, 23.)
Edestin.	3.04	2.40 (Osborne, T. B., and Liddle, L. M., <i>Am. J. Physiol.</i> , 1910, xxvi, 295.)

Hemoglobins.

	Colorimetric.	Other methods.
	<i>per cent</i>	<i>per cent</i>
Horse (1)	8.9	10.5 (Abderhalden, E., <i>Z. physiol. Chem.</i> , 1902-03, xxxvii, 492.)
(2)	8.65	
Cat.	8.5	
	8.55	
Sheep.	8.8	
Ox.	7.93	
		8.15 (Van Slyke, D. D., <i>J. Biol. Chem.</i> 1911-12, x, 52.)

Whole blood (normal human).

1.5731 gm. of histidine per 100 cc. of hydrolyzed blood.

Blood serum (normal human).

0.2338 gm. of histidine per 100 cc. of hydrolyzed blood serum.

EXPERIMENTAL.

Sodium Phosphotungstate Does Not Interfere with the Color Produced When Histidine Reacts with p-Phenyldiazonium Sulfonate.

Phosphotungstic acid—15 gm.—was dissolved in 85 cc. of water contained in a 100 cc. volumetric flask. Histidine dichloride solution—2 cc. of a 1 per cent solution—was then added together with enough water to give a total volume of 100 cc. The liquid remained clear. Of this solution, 5 cc. were transferred to a 25 cc. volumetric flask, neutralized with a sodium hydroxide solution, and diluted to 25 cc. Of this diluted solution

0.50 cc. had a color value equivalent to 10.0 mm. (CR-MO)¹⁰

1.00 " " " " " " " " 19.5 " (CR-MO)

For the 0.50 cc. portion this is equal to 0.02 gm. of histidine dichloride for the entire original liquid, 100 per cent of the amount actually introduced.

For the 1.00 cc. portion this is equal to 0.0195 gm. of histidine dichloride for the entire original liquid, 97.5 per cent of the amount actually introduced.

¹⁰ The details of the colorimetric method and an explanation of the symbols employed here have been described.⁸ This paper also contains tables by means of which colorimetric readings can be readily transformed into gm. of histidine, histamine, etc.

These results show that sodium phosphotungstate, in concentrations as high as 15 per cent, does not interfere with the accuracy of the colorimetric determination of histidine.

The Solubility of Histidine Phosphotungstate.

Experiment A.—Histidine dichloride—0.1000 gm.—was mixed with 82 cc. of water and 18 cc. of 37 per cent hydrochloric acid in a 300 cc. Pyrex flask. The solution was then treated with 100 cc. of a 30 per cent aqueous solution of phosphotungstic acid. The clear liquid was placed in the ice chest. At the end of 24 hours a precipitate of histidine phosphotungstate had formed and collected on the bottom of the flask. To ascertain how much histidine remained in solution 1 cc. of the clear supernatant liquid was transferred to a 10 cc. precision cylinder, neutralized to litmus paper with sodium hydroxide, and diluted to 10 cc. Of this solution

0.50 cc.	had a color value equivalent to	7.0 mm.	(CR-MO)
1.00 " " " " "	" " " " "	14.1 " "	(CR-MO)

This, by table,¹⁰ shows that the equivalent of 0.056 gm. of histidine dichloride was still in solution in 200 cc. of liquid at the end of 24 hours.

The precipitate was triturated with a glass rod, the mixture then being allowed to stand in the ice chest for 43 more hours. At the end of this time 1 cc. of the clear supernatant liquid was removed, neutralized, and diluted to 5 cc. Of this solution

0.50 cc.	had a color value equivalent to	2.5 mm.	(CR-MO)
1.00 " " " " "	" " " " "	4.8 " "	(CR-MO)

This, by table, shows that the 200 cc. of precipitation liquid still contained the equivalent of 0.010 gm. of histidine dichloride which is equal to 0.0068 gm. of histidine base. Longer standing or cooling to 0° in an ice bath produced no change in this value.

To ascertain the effect of rise in temperature upon the solubility of histidine phosphotungstate, the mixture was allowed to stand on the laboratory table for 24 hours at a room temperature that varied from 27–32°. Then 1 cc. of the clear supernatant

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liquid was removed, neutralized, and diluted to 5 cc. as before. Of this solution

0.50 cc. had a color value equivalent to 13.3 mm. (CR-MO)

This, by table, is equivalent to 0.0532 gm. of histidine dichloride—0.0364 gm. of histidine base—for the entire 200 cc. of precipitation liquid.

From this experiment it is clear that histidine phosphotungstate precipitates slowly and that its solubility is markedly influenced by changes in temperature.

Experiment B.—A precipitation was now conducted under the conditions specified by Van Slyke.⁷ Histidinedi chloride—0.1000 gm.—was mixed with 82 cc. of water and 18 cc. of 37 per cent hydrochloric acid in a 300 cc. flask. The solution was then treated with 100 cc. of a 15 per cent aqueous solution of phosphotungstic acid. After standing for 2 hours in the ice chest, crystals had begun to form. They were disintegrated with a glass rod. This gave rise to a rapid and copious precipitation of histidine phosphotungstate. After standing for 24 hours in the ice chest, 1 cc. of the clear supernatant liquid was removed, neutralized, and diluted to 5 cc. Of this solution

0.50 cc. had a color value equivalent to 3.1 mm. (CR-MO)

1.00 " " " " " " " 6.1 " (CR-MO)

This, by table, is equivalent to 0.012 gm. of histidine dichloride per 200 cc. of precipitation liquid. Longer standing in the ice chest produced no change in this value.

The flask was now transferred to an ice bath, where it was kept for 24 hours. At the end of this time, 1 cc. of the clear supernatant liquid was removed, neutralized, and diluted to 5 cc. Of this solution

0.50 cc. had a color value equivalent to 2.1 mm. (CR-MO)

1.00 " " " " " " " 4.2 " (CR-MO)

This, by table, shows that the equivalent of 0.0084 gm. of histidine dichloride—0.00571 gm. of histidine base—was left in solution in the 200 cc. of precipitation liquid.

This experiment shows that, to obtain a most complete and uniform precipitation of histidine phosphotungstate under the

conditions specified by Van Slyke, it is necessary to cool the precipitation mixture in an ice bath. The precipitation, although it is slightly more complete when the concentration of phosphotungstic acid is 7.5 per cent than it is when the concentration is 15 per cent, is not very markedly influenced by the concentration of phosphotungstic acid in the liquid.

*The Effect of Other Amino-Acids upon the Colorimetric Determination of Histidine.*¹¹

Effect of Cystine.

Standard Cystine Solution.—Chemically pure cystine—1.0000 gm.—was dissolved in 30 cc. of N HCl and the resulting solution diluted to exactly 100 cc.

The test solutions were prepared by mixing 1 cc. of a 1 per cent histidine dichloride solution with 2 to 20 cc. of the standard cystine solution and diluting the resulting liquid to 100 cc. The colorimetric determinations were then carried out on 0.20 and 0.40 cc. portions of this test solution.

Table I shows that when cystine and histidine are present in the proportion of 3 (cystine) to 1 (histidine), which is the proportion that is encountered in the cystine-rich keratins, the colorimetric determination of histidine is not interfered with to the slightest extent. The first indication of an interference is obtained when the ratio of cystine to histidine is 6 to 1—a proportion that has not been encountered heretofore in any protein—and under these conditions the interference is only about 3 per cent. A serious interference occurs only when the ratio of cystine to histidine assumes the extremely artificial ratio of 29 (cystine) to 1 (histidine).

From these results we conclude that cystine will not interfere with the colorimetric determination of histidine in any of the known proteins.

¹¹ We wish to call attention to the fact that the interference percentages given in the following pages are correct only when chemicals of highest purity are used in compounding the alkaline reagent. For the past year we have been using Baker and Adamson's highest purity anhydrous sodium carbonate and sodium nitrite (crystals of 97 to 100 per cent purity) and J. T. Baker's sulfanilic acid.

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That the unsaturated sulfur atoms in cystine are responsible for the interference noted for large quantities of this substance is rendered highly probable by the fact that a solution containing equal parts by weight of sodium sulfide and histidine gives rise to a yellowish brown color with *p*-phenyldiazonium sulfonate that is only 40 per cent as intense as that obtained with a pure histidine solution.

TABLE I.
The Effect of Cystine on the Colorimetric Determination of Histidine.

Concentration of histidine per 100 cc.	Concentration of cystine per 100 cc.	Test solution used for the determination.	Theoretical color value.	Color value as determined.	Interference.
<i>mg.</i>	<i>mg.</i>	<i>cc.</i>	<i>mm</i>	<i>mm.</i>	<i>per cent</i>
6.8	20	0.20	10 0	10.0	None.
		0.40	20.0	20 0	
6.8	30	0.20	10.0	10 0	None.
		0.40	20.0	20.0	
6.8	40	0.20	10 0	9 7	3
		0.40	20.0	19 5	
6.8	50	0.20	10.0	9 6	4
		0.40	20.0	19 3	
6.8	100	0.20	10 0	9 2	8
		0.40	20.0	18.1	
6.8	200	0.20	10.0	7.6	24
		0.40	20.0	14 7 Color distinct; too yellow.	

Effect of Leucine.

Standard Leucine Solution.—Chemically pure leucine—2.0000 gm.—was dissolved in 20 cc. of N HCl and the resulting solution diluted to exactly 200 cc.

The test solutions were prepared by mixing 1 cc. of a 1 per cent histidine dichloride solution with 10 to 80 cc. of the standard leucine solution and diluting the resulting liquid to 100 cc. The colorimetric determinations were then carried out on 0.20 and 0.40 cc. portions of the test solution.

Table II shows that leucine does not interfere with the colorimetric determination of histidine until the ratio of leucine to histidine has been raised to the extremely exaggerated proportion of 114 (leucine) to 1 (histidine). While one would not, of course, expect the presence of leucine together with the diamino-acids in

TABLE II.

The Effect of Leucine on the Colorimetric Determination of Histidine.

Concentration of histidine per 100 cc.	Concentration of leucine per 100 cc.	Test solution used for the determination.	Theoretical color value (CR-MO).	Color value as determined	Interference.
mg.	mg.	cc.	mm.	mm.	per cent
6.8	100	0.20	10.0	10.0	None.
		0.40	20.0	20.0	
6.8	500	0.20	10.0	10.0	None.
		0.40	20.0	20.0	
6.8	800	0.20	10.0	9.6	4
		0.40	20.0	19.4 Color slightly too yellow.	

the phosphotungstic acid precipitate, we believed that it might be desirable to show that the presence of a typical α -amino-acid does not interfere with the quantity and intensity of color produced by histidine.

Effect of Arginine.

Standard Arginine Solution.—A solution containing arginine was prepared from salmon sperm by hydrolyzing with sulfuric acid and precipitating the arginine first with silver nitrate and baryta and then with phosphotungstic acid. The solution of

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arginine sulfate obtained by decomposing the phosphotungstate with a cold solution of baryta and removing the barium with a slight excess of sulfuric acid had the following properties.

1. 2 cc. gave 1.70 cc. of amino N_2 at 28° and 752 mm. The solution must, therefore, have contained 0.571 gm. of arginine per 100 cc.

2. Of the above solution, 20 cc. were treated with 0.18 gm. of picrolonic acid dissolved in 3 cc. of alcohol. The picrolonate obtained after drying for 10 hours at 110° weighed 0.2893 gm. and decomposed at 233° .

3. The solution contained no ammonia.

4. When 10 cc. of the solution were mixed with 15 cc. of water and 12.5 gm. of KOH and hydrolyzed for 6 hours as specified by

TABLE III.

The Effect of Arginine on the Colorimetric Determination of Histidine.

Concentration of histidine per 100 cc	Concentration of arginine per 100 cc.	Test solution used for determination	Theoretical color value.	Color value as determined.	Interference
<i>mg.</i>	<i>mg</i>	<i>cc.</i>	<i>mm.</i>	<i>mm</i>	<i>per cent</i>
6.8	115	0 20	10.0	10 0	None.
		0.40	20.0	20.0	
		0.20	10.0	9.7	
6.8	230	0.40	20.0	19.1	3

Van Slyke,⁷ sufficient ammonia was evolved to neutralize 6.8 cc. of 0.1 N HCl. The ammonia evolved from this quantity of a 0.571 per cent solution of arginine should have neutralized 6.56 cc. of the 0.1 N acid.

The test solutions were prepared by mixing 1 cc. of a 1 per cent histidine dichloride solution with 20 and 40 cc. of the standard arginine solution and diluting the resulting liquid to 100 cc. The colorimetric determinations were then carried out on 0.20 and 0.40 cc. portions of the test solution.

Table III shows that arginine does not interfere with the colorimetric determination of histidine until the ratio of arginine to histidine has been raised to the proportion of 34 (arginine) to 1 (histidine). Since a ratio of 6 (arginine) to 1 (histidine) is

the largest that has been encountered in any protein heretofore, we conclude that arginine will not interfere with the colorimetric determination of histidine in any of the known proteins.

The Colorimetric Estimation of Histidine in Proteins.

Casein.

Duplicate experiments were carried out on 3 gm. of carefully purified vacuum-dried casein by the method outlined in the introduction. The volume of the test liquid was 500 cc. Of this solution

0	10	cc.	had	a	color	value	equivalent	to	11.7	mm.	(CR-MO)
0	20	"	"	"	"	"	"	"	23.4	"	(CR-MO)

The color was exactly like that produced by histidine. *The duplicates checked exactly.* This, by table, is equivalent to 0.0000234 gm. of histidine dichloride per 0.10 cc. or 0.117 gm. per entire 500 cc. of test liquid. This is equal to 0.0796 gm. of histidine base in 3 gm. of casein if no correction is made for the solubility of histidine phosphotungstate. We have found that 0.00571 gm. of histidine remains in solution in 200 cc. of precipitation liquid under these conditions; *therefore casein—3 gm.—contains 0.08531 gm. of histidine which is 2.84 per cent.*

Edestin.

Weight dried at 110°, gm.....	3.0000
Precipitation volume, cc.....	200.0
Volume of the test liquid, cc.....	1,000.0
Colorimetric readings:	
0.10 cc. had a color value equivalent to	6.3 mm.
0.20 " " " " " "	12.6 " (CR-MO)
0.30 " " " " " "	18.9 "
Histidine dichloride by table, gm.....	0.126
" base in test liquid, gm.....	0.0856
Solubility correction blank, gm.....	0.00571
Histidine in edestin sample, gm.....	0.09131
" " " " per cent.....	3.04

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*Horse Hemoglobin.*¹²

Sample 1.—Horse hemoglobin—1.9000 gm.—that had been dried *in vacuo* over sulfuric acid for 48 hours, was analyzed for histidine by the method outlined in the introduction. The volume of the pale yellow test liquid was 1,000 cc. Of this solution

0.10 cc. had a color value equivalent to 12.0 mm. (CR-MO)
0.20 " " " " " " " 24.0 " (CR-MO)

The color was exactly like that produced by histidine. This, by table, is equivalent to 0.24 gm. of histidine dichloride—0.1632 gm. of histidine base—for the entire 1,000 cc. of test liquid. This value must be raised by 0.00571 gm.; the solubility correction blank; *therefore horse hemoglobin—1.9000 gm.—contains 0.16891 gm. of histidine which is equal to 8.9 per cent.*

*Sample 2.*¹³—The air-dried material—2.0000 gm.—was dried *in vacuo* over sulfuric acid for 48 hours. The solid so obtained—1.8664 gm.—was heated to constant weight at 110°. The final product—1.8430 gm.—was then analyzed for histidine by the previously described method. The volume of the test liquid was 1,000 cc. of which

0 10 cc. had a color value equivalent to 11 3 mm. (CR-MO)
0 20 " " " " " " " 22 5 " (CR-MO)

This, by table, is equivalent to 0.226 gm. of histidine dichloride—0.1536 gm. of histidine base—for the entire 1,000 cc. of test liquid. To this must then be added 0.00571 gm., the solubility correction blank; *therefore this sample of horse hemoglobin—1.8430 gm.—contained 0.1593 gm. of histidine which is equal to 8.65 per cent.*

Cat Hemoglobin.

Duplicate analyses were carried out on the same sample.

¹² The four varieties of hemoglobin were kindly furnished by W. H. Welker, Professor of physiological chemistry, University of Illinois, Medical Department.

¹³ The two samples of hemoglobin differed both in color and in physical structure.

	<i>First Analysis.</i>	<i>Second Analysis.</i>
Weight air-dried, gm.....	2.0000	
“ vacuum-dried, gm.....	1.8742	
“ dried at 110°, gm.....	1.8561	1.1142
Precipitation volume, cc.....	200 00	100.0
Volume of the test liquid, cc.....	1,000.00	1,000.0
Colorimetric readings:		
0.10 cc. had a color value equivalent to.....	11 2 mm.	6.8 mm.
0.20 cc. had a color value equivalent to.....	22.4 “	13.6 “
Histidine dichloride by table, gm.....	0.224	0.136
“ base in test liquid, gm.....	0.1522	0 0925
Solubility correction blank, gm.....	0 00571	0.00285
Histidine in hemoglobin sample, gm...	0.1579	0 09535
Histidine in hemoglobin sample, <i>per cent.</i>	8 50	8 55

Sheep Hemoglobin.

Weight vacuum-dried, gm.....	2 0000	
Precipitation volume, cc.....	200 0	
Volume of test liquid, cc.....	1,000 0	
Colorimetric readings:		
0.10 cc. had a color value equivalent to..	12 5 mm.	(CR-MO)
0 20 “ “ “ “ “ “ “ “..	25.0 “	(CR-MO)
Histidine dichloride by table, gm.	0 250	
“ base in test liquid, gm.....	0.170	
Solubility correction blank, gm. ...	0 00571	
Histidine in hemoglobin sample, gm.....	0.17571	
“ “ “ “ <i>per cent.</i> ...	8 8	

Ox Hemoglobin.¹⁴

Weight air-dried, gm.....	1 3640	
“ vacuum-dried, gm.....	1.2690	
“ dried at 110°, gm.....	1.2542	
Precipitation volume, cc.....	150 0	
Volume of test liquid, cc.....	1,000 0	
Colorimetric readings:		
0.10 cc. had a color value equivalent to..	7 0 mm.	(CR-MO)
0.20 “ “ “ “ “ “ “ “..	14 0 “	(CR-MO)
Histidine dichloride by table, gm.....	0.140	
“ base in test liquid, gm.....	0.0952	
Solubility correction blank, gm.....	0.00428	
Histidine in hemoglobin sample, gm.....	0 09948	
“ “ “ “ <i>per cent.</i> ...	7 93	

¹⁴ This sample charred slightly while it was being hydrolyzed. The percentage of histidine may, therefore, be somewhat low.

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Whole Blood (Normal Human).

Whole blood—exactly 10 cc.—to which a few crystals of ammonium oxalate had been added to prevent coagulation, was mixed with 15 cc. of 37 per cent hydrochloric acid and hydrolyzed in the customary manner. The resulting liquid was then analyzed for histidine by using the method outlined in the introduction.

Precipitation volume, cc.....	200.0
Volume of test liquid, cc.....	1,000.0
Colorimetric readings:	
0.10 cc. had a color value equivalent to..	11.1 mm. (CR-MO)
0.20 " " " " " " " " ..	22.2 " (CR-MO)
Histidine dichloride by table, gm.....	0.222
" base in test liquid, gm.....	0.1516
Solubility correction blank, gm.....	0.00571
Histidine in 10 cc. of blood, gm.....	0.15731
" " 100 " " " gm.....	1.5731

Blood Serum (Normal Human).

Whole blood—about 30 cc.—was drawn into a centrifuge tube and allowed to clot slowly in the ice chest. The mixture was centrifuged to free the serum as completely as possible from fibrin and blood cells. The perfectly clear, pale yellow serum—exactly 10 cc.—was withdrawn by means of a pipette, mixed with 15 cc. of 37 per cent HCl, and hydrolyzed in the customary manner. The resulting liquid was then analyzed for histidine by using the method outlined in the introduction.

Precipitation volume, cc.....	200.0
Volume of test liquid, cc.....	500.0
Colorimetric readings:	
0.25 cc. had a color value equivalent to...	6.5 mm. (CR-MO)
0.50 " " " " " " " " ...	13.0 " (CR-MO)
Histidine dichloride by table, gm.....	0.0260
" base in test liquid, gm.....	0.01767
Solubility correction blank, gm.....	0.00571
Histidine in 10 cc. of serum, gm.....	0.02338
" " 100 " " " gm.....	0.2338

STUDIES ON PROTEINOGENOUS AMINES.

VIII. A METHOD FOR THE QUANTITATIVE COLORIMETRIC ESTIMATION OF HISTAMINE IN PROTEIN AND PROTEIN-CONTAINING MATTER.

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In a series of articles published recently¹ we communicated a method by means of which small quantities of histamine, β -imidazolethylamine, can be accurately determined in a simple

¹ Koessler, K. K., and Hanke, M. T., *J. Biol. Chem.*, 1919, xxxix, 497, 521, 539.

synthetic culture medium. We stated at that time, that the method as it was employed in the bacterial metabolism studies was not applicable, in its entirety, to more complex mixtures such as blood and urine. The present communication contains the description of a purely chemical method by means of which the histamine content of tissues and other protein-containing matter can be accurately determined.

I. Description of the Method.

1. *Preliminary Treatment of the Material.*—A dry solid was usually hydrolyzed immediately without preliminary treatment. A hydrated tissue, like blood, liver, or hypophysis, was mixed with sufficient alcohol to give a final alcohol concentration of 75 per cent. A few drops of acetic acid were then added and the resulting mixture was heated on the water bath for 1 to 2 hours, to extract the free histamine and to coagulate the proteins. The mixture was then cooled and filtered on a Buchner funnel, the residue being washed with 95 per cent alcohol. This divides the material into two fractions, the *alcoholic extract A* and the *alcohol-insoluble residue R*. Each fraction is then freed from alcohol by heating on the water bath after which it is ready to hydrolyze.

2. *Hydrolysis.*—The dry solid is mixed with ten to twenty parts of 20 per cent hydrochloric acid and hydrolyzed by boiling, under a reflux condenser, for 30 hours over an electrically heated sand bath.

3. *Removal of the Hydrochloric Acid.*—The hydrochloric acid is removed by distillation *in vacuo* at 60° from the same flask. The residue is finally dried *in vacuo* at 80° for 1 hour.

4. *Removal of Ammonia.*—The residue is dissolved in ten to twenty parts of water and the solution treated with an excess of lime and a volume of 95 per cent alcohol equal to one-half the volume of the water added. The mixture is then subjected to a distillation *in vacuo* at 40° until its volume has been reduced to about one-half. This removes the ammonia completely.

5. *Removal of Humin.* The mixture is filtered, on a Buchner funnel, from humin and excess lime, the precipitate being carefully

washed with a large excess of hot water until the washings give a negative Pauly reaction.

6. *Preparation of the Phosphotungstates.*—The alkaline filtrate is acidified by adding a slight excess of hydrochloric acid. The resulting clear liquid is then evaporated to dryness on the water bath in a glass dish. Because of the variability in the quantity and quality of the original protein-containing matter, a concise statement cannot be made as to the amount of phosphotungstic acid to employ. In general, 4 gm. of phosphotungstic acid are sufficient to precipitate the hexone bases from 1 gm. of dry protein. A quantity of phosphotungstic acid equal to twice the weight of the total solids of a hydrated tissue is usually sufficient to precipitate completely the hexone bases. In all cases the concentration of the hydrochloric acid should be 9 cc. of the 37 per cent acid per 100 cc. of precipitation liquid. The final volume of the precipitation liquid should not exceed 2,000 cc. The phosphotungstates are prepared at water bath temperatures and the mixture is then allowed to cool slowly to room temperature after which it is cooled in an ice bath for 24 hours and filtered with suction. The precipitate is washed with an ice-cold fluid containing 18 cc. of 37 per cent hydrochloric acid and 15 gm. of phosphotungstic acid per total aqueous volume of 200 cc.

7. *Decomposition of the Phosphotungstates.*—The phosphotungstate precipitate which contains the histamine, together with histidine, arginine, lysine, cystine, tyramine, and possibly other amines, is suspended in a large volume of hot water—500 to 4,000 cc.—and treated with an excess of a hot saturated solution of baryta. The resulting mixture is digested for 1 hour on the water bath, after which it is cooled in tap water and filtered on a Buchner funnel, the precipitate being thoroughly washed with hot water. The filtrate is heated on the water bath and freed from excess barium by the careful addition of $N H_2SO_4$. The mixture is filtered hot through a folded filter. The filtrate, which should contain a trace of barium, is then evaporated to dryness in a glass dish. The residue is dissolved in the smallest possible quantity of water, the solution transferred to a graduated cylinder, and made up to the smallest convenient volume—10 to 100 cc. (Liquid 7).

8. *Extraction of Histamine with Amyl Alcohol. First Colorimetric Determination.*—10 cc. of Liquid 7 are transferred to a glass-stoppered, shake out bottle,² mixed with 3 gm. of solid sodium hydroxide, and extracted six times with redistilled³ amyl alcohol using 20 cc. for each extraction. The combined amyl alcohol extracts are then extracted five times with $N H_2SO_4$ using 20 cc. for the first and 10 cc. for each of the remaining four extracts. This process is repeated until all Liquid 7 has been extracted.

The combined acid extracts are heated on the water bath and exactly neutralized with baryta. The hot mixture is filtered from barium sulfate, and the filtrate evaporated to dryness in a small glass dish. This residue contains all the histamine. Because of the concentrated character of Liquid 7, a very small quantity of the amino-acids also passes into the amyl alcohol as sodium salts. A colorimetric determination is always positive at this point, because of the presence of histidine. To remove the histidine entirely, the residue obtained above is transferred to the shake out bottle with 10 cc. of water, the solution treated with 3 gm. of solid sodium hydroxide, and extracted with amyl alcohol as above. The sulfuric acid extracts finally obtained are neutralized exactly with baryta. The mixture is filtered from barium sulfate and the filtrate, which should contain no barium, is evaporated to dryness in a small glass dish. The pale yellow residue is dissolved in water and diluted to 25 or 50 cc. Histamine is then estimated colorimetrically in this fraction using the method previously described by us.¹ If the colorimetric test indicates the presence of histamine, the remaining liquid is treated according to Section 9 below. If there is the slightest reason to believe that some of the histidine has again been extracted by the amyl alcohol, which will be apparent from the speed of the color development,¹ a third extraction with amyl alcohol should be carried out. When these extractions are properly conducted the histamine always passes quantitatively into the amyl alcohol.

² For a detailed description of this extraction process see Koessler and Hanke,¹ pp. 525-529.

³ It is best to distill the amyl alcohol *in vacuo*.

9. *Precipitation with Silver Nitrate and Baryta. Second Colorimetric Determination.*—The liquid obtained under Section 8 is diluted to 100 cc. in a 300 cc. Pyrex flask and mixed with 5 cc. of a 20 per cent silver nitrate solution. To the clear liquid is then added barium hydroxide—8 gm.—dissolved in 50 cc. of warm water. The resulting dark brown mixture is filtered with suction on a platinum cone. The precipitate is washed with 50 cc. of a cold saturated solution of baryta. The filtrate should be clear. This divides the material into two fractions, the silver precipitate, which contains the histamine, and the silver filtrate, which although it can contain only traces of histamine seems almost invariably to contain substances that are physiologically active.

The silver precipitate is suspended, with the filter paper, in 50 cc. of water and mixed with 3 cc. of 37 per cent HCl and enough of a 20 per cent Na_2SO_4 solution to remove the barium completely. The mixture is digested on the water bath for 1 hour after which it is filtered and the precipitate washed with hot water. The clear colorless filtrate is neutralized exactly with sodium hydroxide and evaporated to a small volume in a glass dish. The colorless to pale yellow liquid is diluted with water to 25 or 50 cc. Histamine is then estimated colorimetrically in this fraction. If the test shows the presence of histamine, this can be verified biologically on 5 cc. of the liquid and chemically on 20 cc. of the liquid according to Section 10.

This precipitation with silver nitrate and baryta is necessary for two reasons. Test Liquid 8 occasionally contains substances that interfere with the color reaction to such an extent that an accurate determination of histamine is impossible. Such interfering substances appear to be of two kinds; namely, those that *inhibit* the production of color by histamine without giving a color themselves, and those that impart a yellow or green color to the liquid which, of course, makes a perfect match impossible. *These interfering substances were always found to remain in the silver filtrate*; the histamine appears quantitatively in the silver precipitate.

Although one is accustomed to think of histidine, histamine, tyrosine, and tyramine as the only substances that give a positive Pauly reaction, certain of the body tissues appear to contain

small quantities of other substances that give a very similar color reaction. These substances are at least partially removed by the precipitation with silver nitrate and baryta.

10. *Extraction of Histamine by Means of Chloroform and Methyl Alcohol. Third Colorimetric Determination.*—The liquid obtained under Section 9—20 cc.—is evaporated to dryness *in vacuo* in a 500 cc. long necked, round bottomed flask. The perfectly dry residue is treated with 10 cc. of chemically pure methyl alcohol and 0.50 gm. of potassium hydroxide. The alkaline liquid is then treated with 200 cc. of redistilled chloroform and placed in the ice chest for 15 hours. The mixture is filtered through a small folded filter. The precipitate is washed with 200 cc. of hot chloroform. The chloroform extracts are mixed with a few drops of 37 per cent HCl and subjected to a vacuum distillation to remove the chloroform and the methyl alcohol. The residue is dissolved in water and redistilled *in vacuo* to remove the methyl alcohol completely. The residue finally obtained is dissolved in water, diluted to 20 cc., and examined colorimetrically for histamine.

A final purification of the histamine by means of chloroform in doubtful cases seemed desirable because of the fact that chloroform, although it dissolves histamine, will not dissolve many substances that are soluble in amyl alcohol. We tried first to extract histamine from the dry residue obtained by evaporating a histamine solution—1 cc. of a 1 per cent solution—with 2 gm. of sodium carbonate. The quantity of histamine that passed into the chloroform varied from 60 to 80 per cent of the starting material when the extractions were carried on for 24 hours in a Soxhlet extractor under apparently identical conditions.

When lime was used in place of sodium carbonate, only 27 per cent of the histamine passed into the chloroform.

We tried then to extract histamine from an alkaline aqueous solution by means of chloroform. This proved to be impractical because histamine is too soluble in water and too little soluble in chloroform. Such an extraction would be almost endless.

The following principles are incorporated in the successful process that was described in detail above. Methyl alcohol is a good solvent for histamine, salts of histamine, and potassium

hydroxide. When methyl alcohol is used in conjunction with potassium hydroxide, the *histamine is brought into solution as free base*; so there is no possibility of its being occluded by chloroform-insoluble substances. The addition of chloroform to the methyl alcohol solution of histamine precipitates inorganic salts and most of the potassium hydroxide but the histamine remains in solution.

II. Proof that Histamine can be Quantitatively Recovered by the Methods Described in Sections 6, 7, 9, and 10 of Part I.

1. *Histamine Quantitatively Precipitated by Phosphotungstic Acid.*—Phosphotungstic acid—37 gm.—and 37 per cent hydrochloric acid—45 cc.—were dissolved in water and the solution was diluted to 500 cc. Histamine dichloride⁴ solution—0.50 cc. of a 1 per cent solution—was then added to the above liquid. The resulting mixture was cooled in an ice bath for 2 hours and filtered with suction. The precipitate was suspended in 200 cc. of hot water. The remaining steps were carried out as described in Section 7, Part I. The residue finally obtained was dissolved in water and the solution diluted to 100 cc. Of this solution

0.20 cc. had a color value equivalent to 7.5 mm. (CR-MO)

0.40 " " " " " " 15.0 " (CR-MO)

which, by table, is equivalent to 0.0050 gm. of histamine dichloride, 100 per cent of the amount introduced.

From this experiment it would seem that histamine phosphotungstate is practically insoluble in the precipitation liquid employed at a temperature of 0°. This conclusion was verified by performing a qualitative Pauly reaction on 10 cc. of the filtrate from the histamine phosphotungstate. The reaction was entirely negative.

2. *Histamine Quantitatively Precipitated by Silver Nitrate and Baryta.*—The liquid obtained above—100 cc.—which still contained 5 mg. of histamine dichloride, was precipitated with silver nitrate and baryta as described in Section 9, Part I. The liquid

⁴ See Koessler, K. K., and Hanke, M. T., *J. Am. Chem. Soc.*, 1918, xl, 1718, for a description of the method used in preparing the histamine dichloride.

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finally obtained after removing the silver and barium from the silver *precipitate*, was diluted to 100 cc. Of this solution

0.20 cc.	had a color value equivalent to	7.5 mm.	(CR-MO)
0.40 " " " " "	" " " " "	15.0 "	(CR-MO)

which, by table, is equivalent to 0.0050 gm. of histamine dichloride for the entire test liquid, 100 per cent of the amount originally introduced.

This experiment proves that histamine is quantitatively precipitated by silver nitrate and baryta under the conditions specified above.

3. *Extraction of Histamine by Means of Chloroform and Methyl Alcohol.*—Histamine dichloride solution—1.00 cc. of a 1 per cent solution—was evaporated to dryness *in vacuo* in a 500 cc. long necked, round bottomed flask. The dry residue was then treated as described in Section 10, Part I. The residue finally obtained by distillation of the chloroform extracts was dissolved in water and diluted to 100 cc. Of this solution

0.10 cc.	had a color value equivalent to	7.2 mm.	(CR-MO)
0.20 " " " " "	" " " " "	14.4 "	(CR-MO)

which, by table, is equivalent to 0.0096 gm. of histamine dichloride, 96 per cent of the amount originally introduced.

III. *The Method Applied to Casein with and without the Addition of Histamine.*

The search for histamine in a pure protein would seem superfluous if it were not for the fact that Abel and Kubota⁵ have recently claimed to have found it, or a physiologically and chemically similar homologue, as a constituent of casein, egg albumin, and edestin. We were not entirely convinced that the physiologically active substance obtained by the above authors was histamine, because they did not identify their substance as histamine chemically and because the presence of this amine as a normal constituent of a pure protein, that has not been allowed to putrefy, seemed rather improbable. Since casein of high purity is easily

⁵ Abel, J. J., and Kubota, S., *J. Pharmacol. and Exp. Therap.*, 1919, xiii, 243.

prepared, we decided to use this protein as one check on the accuracy of our method.

Analysis of Casein for Histamine.

Carefully purified casein—40 gm.—prepared from fresh skimmed milk, was mixed with 800 cc. of 20 per cent hydrochloric acid and hydrolyzed by boiling for 30 hours.

The hydrochloric acid, ammonia, and humin were removed as described in Sections 3, 4, and 5, Part I.

The phosphotungstates were precipitated from a total volume of 2,000 cc. with 150 gm. of phosphotungstic acid. The precipitation liquid contained 180 cc. of 37 per cent HCl.

The phosphotungstate precipitate was suspended in 4,000 cc. of hot water and freed from phosphotungstic acid, excess barium, etc., as described in Section 7, Part I. The final volume of Liquid 7 was 20 cc.

The double amyl alcohol extraction of Liquid 7 was carried out as described in Section 8, Part I. The final volume of the test solution was 200 cc., of which 0.20 cc. had no color value and 1.00 cc. gave a pale green color that was quite unlike that of an imidazole and which resembled that produced by ammonia and the aliphatic amines. An accurate comparison with the standard indicator solution was, of course, impossible. By comparing intensities, the green color was found to have an intensity value equivalent to about 3.0 mm. (CR-MO).

There can be little doubt that this sample of casein contained no histamine. If the above *green* color is, nevertheless, ascribed to histamine, 0.0008 gm. of this amine, calculated as hydrochloride, is the maximum amount that could have been present in 40 gm. of casein.

The remainder of the test liquid was evaporated to dryness in a small glass dish. The residue was dissolved in 2 cc. of water and the solution injected into a cat that had been anesthetized and prepared so that a blood pressure and respiratory tracing could be obtained at the same time.⁶ The tracing obtained,

⁶ In obtaining the blood pressure tracings in this and in the subsequent work we enjoyed the aid of our colleague, Dr. Julian H. Lewis, which we herewith thankfully acknowledge.

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Fig. 1, shows that the injection produced a drop in blood pressure entirely similar to that produced by histamine. Some substance or substances are present that behave very similarly to histamine

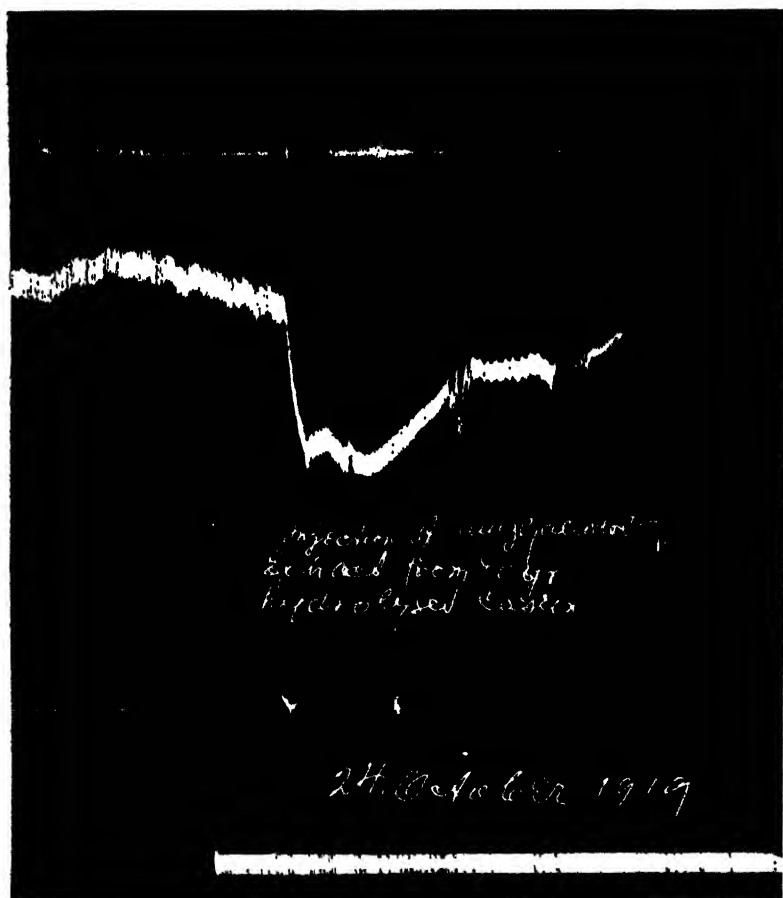


FIG. 1. Blood pressure tracing obtained by injecting the entire amyl alcohol extract and 40 gm. of casein into the femoral vein of a cat.

pharmacologically. We have, therefore, been able to verify the pharmacological findings of Abel and Kubota as illustrated in Fig. 16 of their article; but we cannot conclude with them that casein contains histamine.

Histamine That Has Been Added to Casein Can Be Recovered Quantitatively.

To be certain that our method would recover a small quantity of histamine and that our conclusions concerning casein were correct, another experiment was conducted on 40 gm. of casein exactly like the one that has just been described excepting that 0.01 gm. of histamine dichloride was mixed with the casein before hydrolysis. The final volume of the test liquid was 100 cc., of which

0.05 cc.	had a color value equivalent to	4.0 mm.	(CR-MO)
0.10 " " " "	" " " "	8.0 "	(CR-MO)
0.20 " " " "	" " " "	15.2 "	(CR-MO)

The color for the 0.05 and 0.10 cc. portions was exactly like that produced by histamine. The color obtained with the 0.20 cc. portion was slightly yellow, and, as can be seen from the above value, there was a slight interference with the color production in this case. Since the values obtained with the two smaller portions checked exactly, the calculations were based upon the 0.10 cc. portion. The reading obtained is equivalent to 0.0107 gm. of histamine dichloride for the entire test liquid which is 107 per cent of the amount actually introduced. Hydrolyzed casein alone gave a green color, the intensity value of which was equivalent to 0.0008 gm. of histamine dichloride. This quantity must, therefore, be subtracted from the above gross value to obtain the amount of histamine dichloride actually recovered which is 0.0099 gm. or 99 per cent of the amount actually introduced.

From these two experiments we conclude that the method gives reliable results and that casein contains no histamine although a substance pharmacologically similar to histamine can be split from casein by acid hydrolysis.

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IV. The Method Applied to Human Blood Serum after the Addition of Histamine.

Human blood serum⁷—75 cc.—was mixed with 0.50 cc. of a 1 per cent solution of histamine dichloride. The resulting solution was then treated with 225 cc. of 95 per cent alcohol and a few drops of glacial acetic acid. The mixture was digested for 1 hour on the water bath, cooled to room temperature, and filtered with suction, the coagulum being washed with 95 per cent alcohol. This divided the material into two fractions, *the alcoholic extract A* and *the alcohol-insoluble residue R*.

Alcoholic Extract A.

The alcoholic extract was freed from water and alcohol by distillation *in vacuo* at 50°. The dry residue was treated with 100 cc. of 20 per cent HCl and hydrolyzed as usual. *The material charred considerably during the process of hydrolysis.*

The hydrochloric acid, ammonia, and humin were removed as described in Part I. The phosphotungstates were precipitated from a total volume of 200 cc. with 15 gm. of phosphotungstic acid. The phosphotungstate precipitate was suspended in 800 cc. of hot water and freed from phosphotungstic acid with baryta. The final volume of Liquid 7 was 10 cc. The double amyl alcohol extraction of Liquid 7 was carried out as described in Part I. The final volume of the test solution was 50 cc., of which

0.10 cc. had a color value equivalent to 5.2 mm. (CR-MO)
0.20 " " " " " " " 9.5 " (CR-MO)

The color was exactly like that produced by histamine; but the two readings did not check exactly. A precipitation with silver nitrate and baryta was, therefore, conducted to remove the interfering substances.

The precipitation with AgNO₃ and baryta was carried out as described in Section 9, Part I.

The final volume of the test liquid was 50 cc., of which

0.10 cc. had a color value equivalent to 5.2 mm. (CR-MO)
0.20 " " " " " " " 10.3 " (CR-MO)

⁷ A sample of this serum was analyzed for histamine by the direct process described on p. 544. The serum contained no histamine.

This, by table, is equivalent to 0.0035 gm. of histamine dichloride.

Alcohol-Insoluble Residue R.

The dried material was mixed with 200 cc. of 20 per cent HCl and hydrolyzed as usual.

The hydrochloric acid, ammonia, and humin were removed as described in Part I.

The phosphotungstates were precipitated from a total volume of 400 cc. with 40 gm. of phosphotungstic acid. The precipitate was suspended in 2,000 cc. of water and freed from phosphotungstic acid and baryta. The final volume of Liquid 7 was 20 cc.

The double amyl alcohol extraction of Liquid 7 was carried out as described in Part I. The final volume of the test solution was 50 cc. of which 1.0 cc. had an intensity value of 4.2 mm. The color was far too yellow for histamine. A further purification of this fraction was effected by means of a silver precipitation.

The precipitation with AgNO_3 and baryta was carried out as described in Section 9, Part I. The final volume of the test liquid was 50 cc., of which

0.50 cc. had a color value equivalent to 2.1 mm. (CR-MO)

1.00 " " " " " " " 4.2 " (CR-MO)

The color was too yellow for histamine but the time of development was correct for this imidazole. This, by table, is equivalent to 0.0003 gm. of histamine Cl_2 for the entire test liquid.

In this experiment, 3.5 mg. of histamine dichloride appeared in the alcoholic extract and 0.3 mg. appeared in the alcohol-insoluble residue. The total recovery was 3.8 mg. Since 5 mg. were originally introduced, 1.2 mg. of histamine dichloride were lost somewhere in the process. We have previously shown¹ that histamine is readily adsorbed by charcoal. The alcoholic extract A charred considerably during the process of hydrolysis; so it is possible that the 1.2 mg. of histamine Cl_2 were adsorbed by the charcoal formed at this time. To prove that this statement is correct, the following experiment was carried out in which the possibility of charcoal formation was entirely eliminated.

The same sample of blood serum—75 cc.—was mixed with 0.50 cc. of a 1 per cent solution of histamine dichloride. The resulting solution was treated with 225 cc. of 95 per cent alcohol and a few drops of glacial acetic acid. The mixture was digested

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for 1 hour on the water bath, cooled to room temperature, and filtered with suction, the coagulum being washed with 95 per cent alcohol. The alcoholic extract A was evaporated to dryness in a small glass dish. The residue was transferred to the shake out bottle with 10 cc. of water and the solution treated with 3 gm. of solid NaOH.

A double amyl alcohol extraction was then carried out^a as described in Section 8, Part I. The final volume of the test liquid was 100 cc., of which

0.20 cc.	had a color value equivalent to	7.2 mm.	(CR-MO)
0.40 " " " "	" " " "	" " " "	14.4 " (CR-MO)

The color was exactly like that produced by histamine. This, by table, is equivalent to 0.0048 gm. of histamine dichloride. Since the alcohol insoluble residue was previously proved to adsorb the equivalent of 0.0003 gm. of histamine dichloride, the total recovery in this case was 0.0051 gm. as against 0.0050 gm. actually introduced.

This leaves little doubt that the 1.2 mg. of histamine dichloride that were lost in the hydrolysis experiment had been adsorbed by the charcoal that was formed during the process of hydrolysis.

SUMMARY.

1. A colorimetric method is described by means of which quantities of histamine (β -imidazolethylamine) as small as 0.1 mg. can be accurately determined in protein and protein-containing matter.

2. The presence of histamine could not be demonstrated in 40 gm. of casein by this method.

3. Casein contains a depressor substance that is similar to histamine pharmacologically.

4. Histamine, that has been added to casein before the latter is hydrolyzed, can be recovered quantitatively.

5. The presence of histamine could not be demonstrated in 75 cc. of human blood serum by this method.

6. Histamine that has been added to the blood serum before the latter is hydrolyzed can be recovered quantitatively.

^a We wish to call attention to the fact that in this case Steps 2 to 8 of the general process described in Part I have been eliminated. Although this process is very simple and rapid, it can be used only to estimate loosely combined histamine. Peptamine histamine would probably not pass into the amyl alcohol.

STUDIES ON PROTEINOGENOUS AMINES.

IX. IS HISTAMINE A NORMAL CONSTITUENT OF THE HYPOPHYSIS CEREBRI?

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(Received for publication, June 21, 1920.)

INTRODUCTION.

The physiological activity of extracts of the hypophysis has been a subject of constant investigation since Oliver and Schäfer discovered in 1895 that such extracts had the power of raising the blood pressure of animals on intravenous injection. Howell, 3 years later, brought experimental proof that it was only the posterior part of the hypophysis which possessed this pressor action. This elevation of pressure seemed to result from the direct action of the active substance upon the involuntary muscle of the heart and arteries without the intervention of the sympathetic nervous system. This specific affinity of the active principle of the hypophysis for the smooth muscle fiber cell was confirmed anew through the important discovery of Dale that pituitary extracts have the faculty of producing intense contractions of the uterus. The detection of this oxytocic action led to the introduction of pituitary extracts into human therapeutics. Since then, the isolation of the active principle of the hypophysis has been repeatedly attempted by biochemists.¹ Although our knowledge has been greatly increased by these investigations, the actual chemical composition of the active principle of the hypophysis is still unknown.

¹ For a review of the work and literature on the chemistry of the pituitary gland see Crawford, A. C., *J. Pharmacol. and Exp. Therap.*, 1920, xv, 81.

There are two facts that seem to stand out from the sum total of these investigations. The active principle of the gland behaves like an amine, and it seems always to be associated with an imidazole derivative. These two chemical properties claimed for the active principle of the hypophysis, in conjunction with the physiological activity of the extracts on the uterus, suggested a connection with β -imidazolyethylamine (histamine). Since this amine is derived from histidine by decarboxylation, Barger suggested that "The pituitary active principle is possibly a polypeptid like derivative of histidine." Decarboxylated polypeptides of this type have been synthesized by Guggenheim who proposed for them the name peptamines. They show the same physiological behavior as the amine from which they are derived; but to a much less degree.

This whole question seemed to be definitely settled in a very simple manner when Abel and Kubota² published a paper in which they state that "histamine is the plain muscle-stimulating and depressor constituent of the posterior lobe of the pituitary gland." This statement is based upon the actual isolation and identification of 18 mg. of histamine dipicrate from 1 pound of dried substance of the whole pituitary gland. It is difficult to accept the conclusions of these authors, because of the differences in chemical as well as physiological behavior of pituitary extracts and histamine.

There is a widespread conception that histamine is a very labile substance. Thus, for example, Myers and Voegtlin³ suggested recently in connection with some work on the chemical isolation of vitamins that the physiological activity of a crystalline product containing histamine or histamine-like substances was destroyed by drying. This certainly does not hold true for histamine; for this amine loses none of its physiological activity when it is dried at room temperature or at a temperature of 100° in air or *in vacuo*. We have shown in a previous publication⁴ that histamine, when it is heated on the boiling water bath with concentrated sodium hydroxide for 7 hours, is only destroyed to

² Abel, J. J., and Kubota, S., *J. Pharmacol. and Exp. Therap.*, 1919, **xiii**, 243.

³ Myers, C. N., and Voegtlin, C., *Proc. Nat. Acad. Sc.*, 1920, **vi**, 3.

⁴ Koessler, K. K., and Hanke, M. T., *J. Biol. Chem.*, 1919, **xxxix**, 539.

the extent of 7.5 per cent, while 10 hours of boiling with hot concentrated hydrochloric acid leaves the histamine unchanged. Guggenheim⁵ showed in 1914 that the pressor and oxytocic properties of "pituglandol" are completely destroyed even by dilute alkali—2.0 N NaOH—at room temperature, while the physiological activity of histamine on bronchi and blood pressure was not in the least impaired by the same treatment. The differences in physiological activity of the extracts of the hypophysis and of histamine, with especial regard to their broncho-constrictor action, have been admirably discussed by Jackson and Mills.⁶

Experiments on cases of diabetes insipidus in man have shown that the reaction of the pituitary extract in suppressing the polyuria for days cannot be duplicated by injections of histamine (Rowntree).

The typical urticaria-like wheal produced on application of histamine to the scarified skin of man cannot be obtained with pituitary extracts.⁷

We have developed quantitative methods, in our laboratory, for the estimation of histamine and other imidazoles in tissues and were applying these methods to a detailed study of the presence of histamine in the animal organism at the time of the appearance of the article by Abel and Kubota. Considering the far reaching importance of the hypophysis problem it seemed logical to extend our research to the hypophysis. From the results of this part of our work we have to conclude that *the perfectly fresh hypophysis contains no histamine*. Still there can be no question that Abel and Kubota isolated histamine from the pound of pituitary substance which they secured in a dry state on the market. The question is, how did the histamine get into the pituitary material used by these investigators? It is a well known fact⁴ that histamine is readily formed from histidine by the action of certain putrefactive microorganisms; and histidine is a normal constituent of practically all protein of animal origin. The method used at the slaughter houses for

⁵ Guggenheim, M., *Biochem. Z.*, 1914, lxx, 189.

⁶ Jackson, D. E., and Mills, C. A., *J. Lab. and Clin. Med.*, 1919, v, 1.

⁷ Sollmann, T., and Pilcher, J. D., *J. Pharmacol. and Exp. Therap.*, 1916-17, ix, 309.

preparing dried glandular products gives ample opportunity for changes, both autolytic and bacterial. Our work on the relation of histamine to peptone shock (page 567) emphasizes again how essential it is to control bacterial action and how imperative it is to work only with material that has been prepared by the investigators themselves.

We have been able to demonstrate the presence of histamine in the liver and feces of one dog by the method used in the present investigation and we expect to report on this phase of the work in the near future; but we were unable to demonstrate the presence of the slightest trace of histamine in the hypophysis. *On the basis of this work, the claim of Abel and Kubota to have found in histamine the plain muscle stimulating and depressor constituent of the posterior lobe of the pituitary gland seems to us untenable.*

EXPERIMENTAL.

Collection of the Material.

The perfectly fresh glands—beef—were collected at Swift and Company's Chicago plant. They were trimmed free from extraneous tissue, weighed, and dropped into boiling absolute alcohol approximately 25 minutes after the animal had been struck. The total weight of the moist glands was 346 gm.

The alcohol was removed by distillation *in vacuo* at 40°. The residue was put through a food chopper. The finely divided material was then digested for 2 hours with 2,000 cc. of 75 per cent alcohol to which a few cc. of glacial acetic acid had been added. The mixture was cooled and filtered with suction, the residue being washed thoroughly with 95 per cent alcohol. This divided the material into two fractions, the alcoholic extract A and the alcohol-insoluble residue R.

The Alcoholic Extract A.

The alcohol and water were removed by distillation *in vacuo* at 50°. The residue was emulsified with hot water and diluted to 140 cc. in a graduated cylinder. This fraction might contain histamine either free or in the form of a peptamine. Since it seemed desirable to know not only how much histamine was

present but also the form in which it was present in the gland, this fraction was divided into two equal parts. One-half was extracted directly with amyl alcohol without hydrolysis, the other half was hydrolyzed, treated with phosphotungstic acid, and then extracted with amyl alcohol.

Loosely Bound Histamine. Non-Hydrolyzed Alcoholic Extract A.—This fraction which was not hydrolyzed, was extracted with amyl alcohol, 10 cc. at a time, as described in Part I of the preceding article, page 544. The combined amyl alcohol extracts were then extracted with $N H_2SO_4$,^{*} the acid extracts neutralized with baryta, the mixture was filtered from $BaSO_4$, and the filtrate evaporated to dryness in a glass dish. The residue was transferred to a shake out bottle with 10 cc. of water. Sodium hydroxide—3 gm.—was added and the liquid extracted six times with 20 cc. of amyl alcohol. The combined amyl alcohol extracts were extracted with $N H_2SO_4$, using 20 cc. for the first and 10 cc. for each of the remaining four extracts. The acid extracts were neutralized with baryta, the mixture was filtered from $BaSO_4$, and the filtrate, which was free from barium, was evaporated to dryness in a small glass dish. The residue was dissolved in water, the solution transferred to a 50 cc. graduated precision cylinder, and diluted with water to 50 cc. Of this solution

0	20	cc.	had	a	color	value	equivalent	to	3.1	mm.	(CR-MO)
0.50	"	"	"	"	"	"	"	"	7.5	"	(CR-MO)

The color resembled that produced by histamine excepting in its time of development which was too rapid for histamine. This, by table, is equivalent to 0.001 gm. of histamine dichloride for the entire test liquid.

The remaining liquid was subjected to a phosphotungstic acid precipitation as described in Sections 6, 7, and 8, Part I, of the preceding paper. A colorimetric determination showed that *all* the color-producing substance had been precipitated by the phosphotungstic acid.

^{*} The details of this process are given in Section 8, Part I, of the preceding article.

The liquid was then subjected to a precipitation with silver nitrate and baryta as described in Section 9, Part I, of the preceding paper.

The fraction *precipitated by silver* was finally brought to a volume of 50 cc. Of this solution

0.50 cc. had no perceptible color value.

1 00 cc. gave a very faint green color.

This would indicate that the color-producing substance that was soluble in amyl alcohol and precipitated by phosphotungstic acid *could not have been histamine* because it did not give an insoluble silver compound.

The silver filtrate, which contained the color-producing substance, did not contract the excised virgin guinea pig uterus.

We conclude, therefore, that the perfectly fresh hypophysis contains no loosely bound or free histamine.

Peptamine Histamine. Hydrolyzed Alcoholic Extract A.—This fraction—70 cc., one-half of the entire alcoholic extract A—was mixed with 70 cc. of 37 per cent HCl and hydrolyzed by boiling for 30 hours over an electrically heated sand bath. The material was freed from HCl, NH_3 , and humin, precipitated with phosphotungstic acid,⁹ and extracted with amyl alcohol as described in Sections 1 to 9, Part I, of the preceding paper.

The final volume of test Liquid 8 was 100 cc., of which

0 50 cc. had a color value equivalent to 2.7 mm. (CR-MO)

1.00 " " " " " " 5.5 " (CR-MO)

The color resembled that produced by histamine excepting in its time of development which was too rapid for histamine. This, by table, is equivalent to 0.00074 gm. of histamine dichloride for the entire test liquid.

The remainder of the above solution was subjected to a precipitation with silver nitrate and baryta as described in Section 9, Part I, of the preceding paper. The fraction *precipitated by silver* was finally brought to a volume of 50 cc., of which

0.50 cc. had a color value equivalent to 2.0 mm. (CR-MO)

1 00 " " " " " " 3.8 " (CR-MO)

⁹ The volume of the precipitation liquid was 250 cc. 20 gm. of phosphotungstic acid were employed.

This, by table, is equivalent to 0.00025 gm. of histamine dichloride for the entire test liquid.

The remaining liquid was evaporated to dryness. The residue was dissolved in 5 cc. of water. *Of this solution, 1 cc. did not contract the excised virgin guinea pig uterus.* This proves that the alcoholic extract from the hypophysis contained no histamine. The slight color value of this fraction, which we found to be equivalent to 0.00025 gm. of histamine dichloride, must therefore have been due to some physiologically inert substance. *It could not have been due to histamine.*

Recapitulation.

The 75 per cent alcoholic extract from 346 gm. of fresh hypophysis does not contain histamine.

The Alcohol-Insoluble Residue R.

The dry residue, which weighed 132 gm., was mixed with 1,500 cc. of 20 per cent hydrochloric acid and hydrolyzed in the customary manner.

The material was freed from HCl, NH₃, and humin, and precipitated with phosphotungstic acid¹⁰ as described in Sections 1 to 8, Part I, of the preceding paper. The residue finally obtained from the phosphotungstate *precipitate*, was nearly solid and large in volume. Fully 300 cc. of water were required to bring this residue into solution. This would have required so many amyl alcohol extractions that a new procedure was adopted. The solution was treated with 20 gm. of anhydrous sodium carbonate. The resulting liquid was evaporated on the water bath and the residue dried for 48 hours *in vacuo* over sulfuric acid. The perfectly dry, brown solid was then extracted with chloroform for 72 hours in a Soxhlet extractor. This divided the material into two fractions, the *chloroform extract*, which should contain *most* of the histamine, and the *chloroform-insoluble residue*.

¹⁰ The volume of the precipitation liquid was 2,000 cc. 250 gm. of phosphotungstic acid were employed.

The Chloroform Extract.

The combined chloroform extracts were evaporated on the water bath. The residue was dissolved in water and diluted to 50 cc. Of this solution 1.00 cc. gave a faint *green* color that could most certainly not have been produced by histamine. The solution was evaporated to dryness. The residue was dissolved in water and diluted to 5 cc. *Of this solution, 1.00 cc. did not contract the excised virgin guinea pig uterus.*

This proves that the chloroform extract, which should certainly have contained *some* histamine if any had been present in the original solid, was entirely free from histamine.

The Chloroform-Insoluble Residue.

To be perfectly certain that the histamine had not been adsorbed by the solids in this residue so that none of it was extracted by the chloroform, the solid was extracted three times with hot 95 per cent alcohol, using 200 cc. for each extraction. The combined alcoholic extracts were evaporated on the water bath. The residue was dissolved in water, the solution treated with sodium hydroxide, and the alkaline liquid extracted as usual with amyl alcohol. The test liquid finally obtained had a volume of 50 cc. of which

0.20 cc.	had an intensity value equivalent to 5.0 mm.	(CR-MO)
1.00 " " " " " "	" " " " " "	8.0 " (CR-MO)

As can be readily seen, the above values are worthless because the 1 cc. portion gave almost the same color as the 0.20 cc. portion. To eliminate the interfering substances, a silver precipitation was now conducted as described in Section 9, Part I, of the preceding paper. The final volume of the test liquid was 25 cc., of which

0.10 cc.	had a color value equivalent to 8.2 mm.	(CR-MO)
0.20 " " " " " "	" " " " " "	16.2 " (CR-MO)

The color was brown, attained its full intensity almost immediately, and was perfectly stable so that it did not resemble the color produced by histamine in any particular. If, nevertheless,

the color value is calculated as histamine dichloride, the presence of 0.00275 gm. of this substance is indicated.

That the above color value was not due to histamine was proved as follows:

1. 1 cc. of the test liquid did not contract the excised virgin guinea pig uterus.

2. That the substance responsible for the color production was different from histamine chemically was proved by subjecting the remainder of the liquid—23 cc.—to the chloroform methyl alcohol purification described in Section 10, Part I, of the preceding paper. The residue finally obtained was dissolved in water and diluted to 23 cc. Of this solution

0.50 cc. had a color value equivalent to 8.6 mm. (CR-MO)

1.00 " " " " " " " 17.0 " (CR-MO)

The color was like that previously obtained and not like that produced by histamine. By table, this would be equivalent to 0.00057 gm. of histamine dichloride for the entire test liquid, which is the maximum amount of this amine that could have been present in the entire 346 gm. of moist glands originally employed. That histamine could not have been responsible for even this slight color value was previously proved by the fact that the liquid after the silver precipitation did not contract the excised virgin guinea pig uterus.

CONCLUSION.

Perfectly fresh beef hypophysis does not contain histamine.

STUDIES ON PROTEINOGENOUS AMINES.

X. THE RELATION OF HISTAMINE TO PEPTONE SHOCK.

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(Received for publication, June 21, 1920.)

INTRODUCTION.

The discovery that the intravenous injection of proteose-peptone into animals produces profound systemic disturbances of shock-like character was made by Schmidt-Muhlheim¹ and Fano² in the laboratory of Ludwig. Ludwig and his pupils were studying the mode of absorption of proteins from the intestinal tract, their fate, and their resynthesis in the animal organism. In an endeavor to settle the question whether proteins are mainly absorbed as proteoses or peptones or as amino-acids, proteose-peptone solutions were injected into the circulation of animals (dogs). While the primary inquiry was not definitely answered by these experiments, they resulted in the observation that the animals injected showed a very marked fall of blood pressure, acceleration of lymph flow, incoagulability of the blood, sub-normal temperature, increased frequency of respiration, and a state of loss of consciousness (peptone shock).

In interpreting this toxic action of the proteose-peptones two distinct views have crystallized from the work of a large number of investigators.³ One group believes that the toxicity of the proteose-peptone is a property inherent in the molecular struc-

¹ Schmidt-Muhlheim, A., *Arch. Physiol.*, 1880, 33.

² Fano, *Arch. Physiol.*, 1881, 277.

³ For the complete literature of the subject see Chittenden, R. H., Mendel, L. B., and Henderson, Y., *Am. J. Physiol.*, 1898-99, ii, 142; and especially Underhill, F. P., and Hendrix, B. M., *J. Biol. Chem.*, 1915, xxij, 443.

ture of these products of protein digestion. The other group ascribes their toxic action to the presence of contaminating substances which can be extracted from the proteose-peptone mixture; the latter thus freed from the supposedly true poison is said to have no physiological activity. Brieger's peptotoxin,⁴ Pick and Spiro's peptozyme,⁵ and Popielski's vasodilatin⁶ are substances of undetermined chemical composition that are supposed to represent the poison which can be separated from the peptone. Though the work of Nolf, Underhill, Zunz, and Gibson seemed to have proved definitely that proteose-peptones of vegetable as well as of animal origin are toxic in themselves, the doctrine of a separable toxin in peptone has been recently revived by Abel and Kubota,⁷ who state that *histamine is the toxic agent of Witte's peptone*. A possible relation of β -imidazolylethylamine to peptone shock had been previously suggested by Dale and Laidlaw,⁸ who emphasized the great similarity in the symptoms of peptone shock to those produced by the injection of histamine. The whole symptom-complex of peptone intoxication was revived and the older work on this subject brought again to the attention of the biologists through the studies of Biedl and Kraus⁹ on anaphylaxis. They recalled first the striking resemblance of the symptoms produced in animals sensitized to a certain protein on reinjection of this protein with the syndrome obtained by Ludwig's pupils on peptone injection. In a later publication they consider anaphylaxis as a true peptone intoxication. Dale and Laidlaw never regarded the correspondence of symptoms as a sufficient basis for theoretical speculations. That they are still of the same opinion can be seen from the following statement in their paper on histamine shock.¹⁰

⁴ Brieger, L., *Z. physiol. Chem.*, 1882-83, vii, 274. For a criticism of Brieger's peptotoxin work, see Salkowski, E., *Virchows Arch. path. Anat.*, 1891, cxxiv, 409.

⁵ Pick, E. P., and Spiro, K., *Z. physiol. Chem.*, 1900-01, xxxi, 235.

⁶ Popielski, L., *Arch. ges. Physiol.*, 1909, cxxvi, 483.

⁷ Abel, J. J., and Kubota, S., *J. Pharmacol. and Exp. Therap.*, 1919, xiii, 243.

⁸ Dale, H. H., and Laidlaw, P. P., *J. Physiol.*, 1910-11, xli, 318.

⁹ Biedl, A., and Kraus, R., *Wien. klin. Woch.*, 1909, xxii, 363. Kraus, R., and Levaditi, C., *Handbuch der Technik und Methodik der Immunitätsforschung*, Jena, 1911, i, 255-290.

¹⁰ Dale, H. H., and Laidlaw, P. P., *J. Physiol.*, 1919, lii, 355.

"The existence of these points of community, in the action of substances so utterly unrelated chemically as histamine and certain metallic ions, forbids any assumption that the production of similar effects, by unknown constituents of some organ or tissue, indicates the presence therein of histamine itself, or of any substance chemically related to it. The similarity depends on the fact that all act on the endothelium, and produce in it changes probably of the same general type. A hint, as to what the nature of these changes may be, is possibly provided by the fact that the anaphylactic reaction, more especially in those species in which histamine exhibits this type of action, also presents the picture of an acute endothelial poisoning. All available evidence goes to show that the anaphylactic antibody is of the nature of a "precipitin," the interaction of which with the corresponding antigen results in a change in the state of dispersion of the colloidal particles."

Abel and Kubota, though well acquainted with Dale and Laidlaw's paper, take the view that histamine is present wherever living protoplasm exists, or at least wherever protoplasm is killed. Believing that it makes its appearance wherever a true protein is disrupted by enzymes, acids, or other hydrolytic agents, they believe they have demonstrated its presence in ereptone, Witte's peptone, casein, and edestin. Traumatic shock, anaphylaxis, Vaughan's protein poison, the active principle of the posterior part of the hypophysis, and many other questions of fundamental importance to medicine they believe are settled on the basis of the presence and physiological activity of histamine. To bring about the solution of all these questions in such a simple manner is so suggestive and attractive that it is only with a certain sense of reluctance that we venture the opinion that the far reaching conclusions of Abel and Kubota are not justified by the data of their experimental work. In only one case have they actually demonstrated the presence of histamine; namely, in a dried commercial sample of hypophysis glands.

We have discussed the relation of histamine to the hypophysis problem in the preceding paper. In working on the presence of histamine in protein products Abel and Kubota used two commercial preparations, ereptone and Witte's peptone. Physiological tests made with solutions prepared from an impure picrate led them to believe that the shock poison of ereptone and Witte's peptone is histamine. The results obtained with these commercial preparations are directly transferred to peptone

shock in general. Bacterial putrefaction was not excluded in the preparation of the protein derivatives used; thus the fundamental question, so far reaching for this whole problem and recognized as such by the above authors in the introduction to their paper,¹¹ namely if histamine can be formed in the absence of bacteria by the enzymatic activity of organ cells alone, is still unanswered.

Vaughan's poisonous protein fraction is not identical with histamine, for its toxicity is completely destroyed by boiling with dilute (3 per cent) hydrochloric acid,¹² while heating histamine with concentrated hydrochloric acid for 10 hours on the boiling water bath leaves the imidazole compound intact,¹³ and does not impair its toxicity.

To expect a similarity in physiological action from compounds having a similar chemical structure is logical and justified by evidence; but to conclude from a similar pharmacodynamic action to the identity of chemical structure or the invariable presence of one and the same substance is a perilous undertaking.

Plan of Procedure.

The main postulates of an endeavor to clear up the relation of histamine to peptone shock seemed to be:

1. The preparation of a proteose-peptone under sterile conditions. Since certain microorganisms have the faculty of forming histamine from protein matter, no conclusions can be drawn regarding the origin of histamine found in a sample of peptone if this postulate is not fulfilled. We controlled the absence of bacteria during the time of the preparation of our peptone by daily preparations of aerobic and anaerobic cultures.

2. The peptone must be physiologically active. That this was actually the case can be seen by consulting Figs. 1 and 2.

¹¹ Abel and Kubota,⁷ pp. 247-249.

¹² Underhill, F. P., and Hendrix, B. M., *J. Biol. Chem.*, 1915, xxii, 465.

¹³ Koessler, K. K., and Hanke, M. T., *J. Biol. Chem.*, 1919, xxxix, 521.

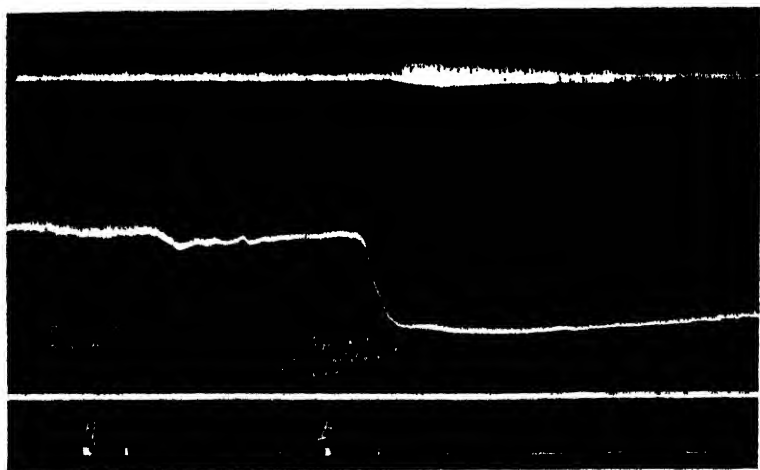


FIG. 1. (A) Injection of pepsin. (B) Injection of 2 gm. of histamine-free peptone prepared from fibrin.

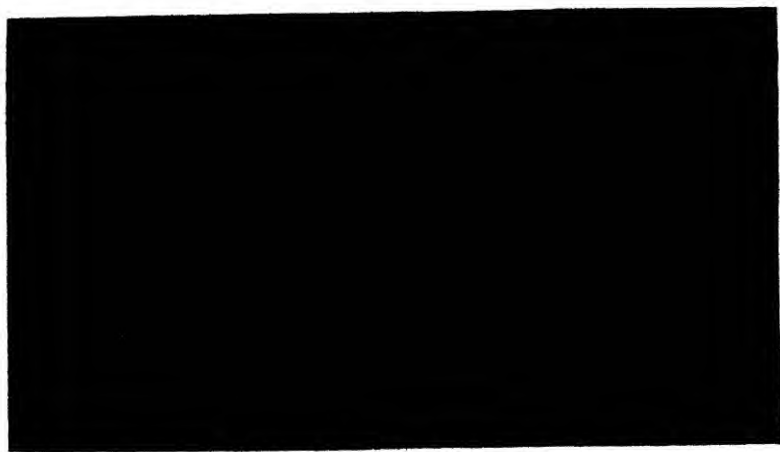


FIG. 2. Contraction of the excised virgin guinea pig uterus produced by 0.1 gm. of a histamine-free, fibrin peptone. The uterus was suspended in 100 cc. of Locke-Ringer solution.

EXPERIMENTAL.

*Preparation of Histamine-Free Peptone from Fibrin.*¹⁴

Well washed blood fibrin—275 gm.—was treated with 11,000 cc. of 0.2 per cent sodium hydroxide. The mixture was covered with a layer of toluene and allowed to stand at room temperature for 8 days. The opalescent mixture was filtered through several layers of toweling. The filtrate—10,000 cc.—was diluted with 10,000 cc. of water. Acetic acid—0.5 per cent—was then added in small portions until a perfect flocculation had occurred. The precipitate was washed four times, by decantation, with distilled water and was then largely freed from water by filtration on a Buchner funnel. The residue obtained—116 gm.—was mixed with 350 cc. of 0.4 per cent hydrochloric acid and 30 cc. of a 0.1 per cent pepsin solution in 0.4 per cent hydrochloric acid. The mixture was covered with toluene and incubated at 37° for 1 week. That the liquid was free from living microorganisms throughout this entire period was proved by repeated aerobic and anaerobic cultures. The resulting mixture was nearly neutralized with a 10 per cent sodium carbonate solution, heated to boiling, and filtered through a large, water-soaked, folded filter paper. The filtrate was evaporated to dryness *in vacuo* over sulfuric acid, at room temperature. The dry, pale yellow powder weighed 14.5 gm. This will be referred to as the “fibrin peptone.”

Analysis of Fibrin Peptone for Histamine.

5 gm. of the peptone were dissolved in 100 cc. of 20 per cent hydrochloric acid and hydrolyzed by boiling for 30 hours over an electrically heated sand bath. The acid, ammonia, and humin were removed as previously described.¹⁵ The phosphotungstates were precipitated from a total volume of 400 cc. with 40 gm. of

¹⁴ We are indebted to Dr. F. C. Koch, Department of Physiological Chemistry, University of Chicago, for the details of the method used in the preparation of the peptone.

¹⁵ A detailed description of the method used in the estimation of histamine in protein-containing matter has been reported (Hanke, M. T., and Koessler, K. K., *J. Biol. Chem.*, 1920, xliii, 543).

phosphotungstic acid. The phosphotungstate precipitate was freed from phosphotungstic acid, etc. The residue finally obtained was subjected to a double amyl alcohol extraction. The volume of the test liquid was 50 cc. of which, tested by our meth-

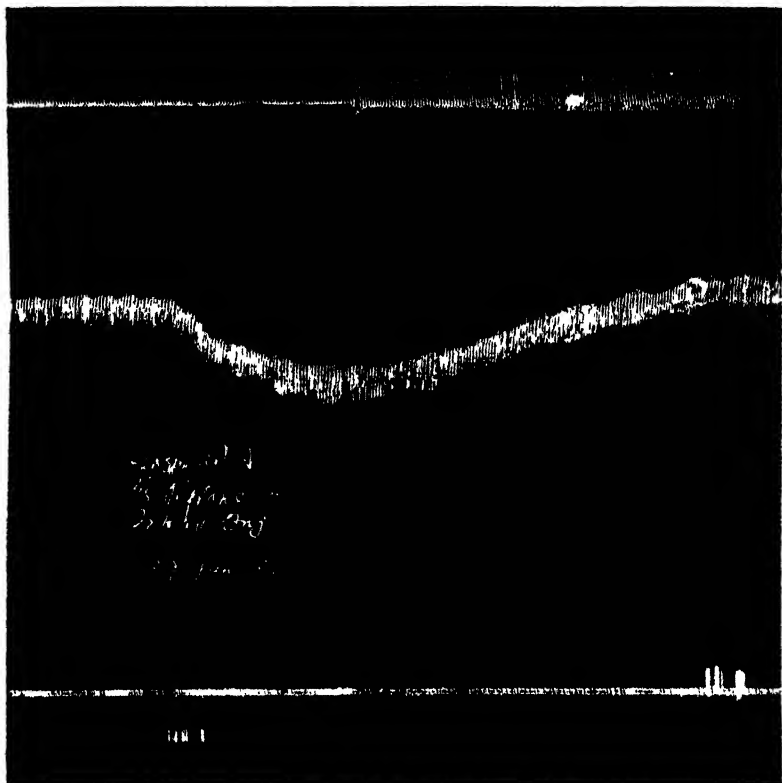


FIG. 3. The peptone was hydrolyzed, precipitated with phosphotungstic acid, and the phosphotungstate precipitate extracted twice with amyl alcohol from an alkaline solution. The liquid was free from histamine. The 2 cc. injected represent the amyl alcohol extract from 2 gm. of peptone.

ods, 0.50 cc. gave no perceptible color and 1.00 cc. gave a very faint green color. *This proves that the above peptone was entirely free from histamine.*

The remaining liquid was evaporated on the water bath. The dry residue was dissolved in 5 cc. of water. Of the resulting solution, 1.00 cc. *did not contract the excised virgin guinea pig uterus*; which substantiates the conclusion previously arrived at that histamine was absent. Of the same solution, 2 cc. were injected into the femoral vein of a dog. Fig. 3 shows that this injection produced a slight drop in blood pressure which must, therefore, have been produced by some substance not identical with histamine.

A Typical Peptone Shock from a Histamine-Free Peptone.—2 gm. of the above peptone, that had been proved to contain no histamine, were dissolved in 6 cc. of isotonic salt solution and injected into the femoral vein of a dog that had been anesthetized and arranged so that blood pressure and respiratory tracings could be obtained. As can be seen by examining Fig. 1, this injection gave rise to a typical peptone shock. A morphological blood examination showed before the injection of the peptone, hemoglobin 88, leucocytes 20,600, erythrocytes 6,250,000; 1 hour after the injection, hemoglobin 108, leucocytes 5,700, and erythrocytes 7,200,000.

The Action of Peptone on the Unstriated Muscle of the Guinea Pig Uterus.—That Witte's peptone has the property of contracting the isolated uterus of the virgin guinea pig in a manner that is indistinguishable from that of histamine has been shown by Dale and Laidlaw.⁸ Abel and Kubota, who worked with a chloroform extract from Witte's peptone, ascribe this oxytocic reaction of peptone to histamine. That this action is also inherent in the structure of the peptone molecule and not dependent upon the presence of histamine, we showed by using our fibrin peptone, which had been proved to be free from histamine.

5 cc. of a 2 per cent solution of fibrin peptone—0.1 gm. of peptone—were introduced into 100 cc. of Locke-Ringer solution in which an excised guinea pig uterus was suspended. A typical contraction of the uterus was obtained which is illustrated by the curve of Fig. 2.

To prove that the reactions were produced by the peptone obtained from fibrin and not by some constituent of the pepsin employed in the preparation of the peptone, 30 cc. of a 0.1 per cent pepsin solution in 0.4 per cent HCl were incubated for

1 week, neutralized with sodium carbonate, evaporated to dryness, dissolved in 2 cc. of water, and injected into the femoral vein of a dog. An examination of Fig. 1, Part A, shows that this injection did not produce a fall in blood pressure.

Analysis of Witte's Peptone for Histamine.—Witte's peptone—5 gm.—was hydrolyzed, freed from hydrochloric acid, ammonia, and humin, precipitated with phosphotungstic acid, and extracted with amyl alcohol, the details being identical with those just described for the fibrin peptone. The volume of test Liquid 8 was 25 cc., of which

0.50 cc. had an intensity value equivalent to 2.6 mm. (CR-MO)
 1.00 " " " " " " " 4.1 " (CR-MO)

The color was orange-yellow and hence difficult to match against the standard indicator solution. The remaining liquid—23.5 cc.—was subjected to a precipitation with silver nitrate and baryta.¹⁵ The volume of test Liquid 9 was 23.5 cc., of which

0.50 cc. had a color value equivalent to 2.5 mm. (CR-MO)
 1.00 " " " " " " " 5.0 " (CR-MO)

The color was somewhat more yellow than that produced by histamine; but the time of development was correct for this imidazole. This, by table, is equivalent to 0.0001675 gm. of histamine dichloride for the entire test liquid.

The remaining liquid—22 cc.—was evaporated on the water bath. The residue was dissolved in 5 cc. of isotonic salt solution. Of this solution, 1.00 cc. contracted the excised virgin guinea pig uterus. The curve obtained, Fig. 4, was exactly like that obtained with a solution of pure histamine dichloride.

This sample of Witte's peptone contained the equivalent of 0.00335 gm. of histamine dichloride per 100 gm. of peptone.

Histamine that Has Been Added to Peptone Can Be Recovered Quantitatively.—This experiment was a duplicate of the one that has just been described excepting that 0.0050 gm. of histamine dichloride was added to the 5 gm. of Witte's peptone before hydrolysis. The final volume of test Liquid 8 was 100 cc., of which

0.20 cc. had a color value equivalent to 7.7 mm. (CR-MO)
 0.40 " " " " " " " 15.4 " (CR-MO)

The color was exactly like that produced by histamine. This, by table, is equivalent to 0.005125 gm. of histamine dichloride for the entire test liquid. From this, the amount of histamine dichloride previously found to be present in this sample of Witte's peptone—0.0001675 gm.—must be subtracted, which leaves 0.00496 gm. as the amount of the *introduced* histamine dichloride that was recovered, which is 99.3 per cent.

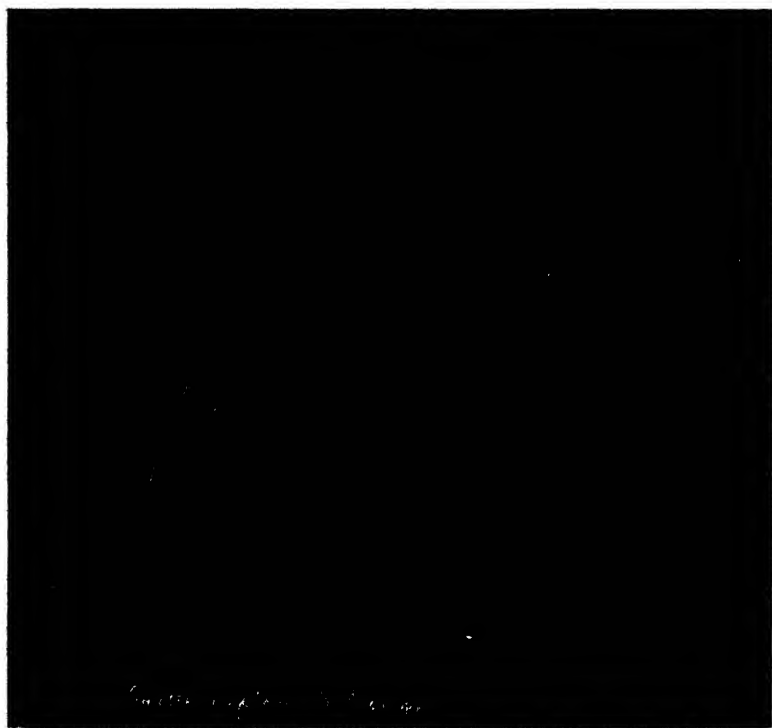


FIG. 4. Contraction of excised virgin guinea pig uterus produced by the silver precipitate from 1 gm. of Witte's peptone. The presence of histamine was also indicated by the colorimetric determination.

CONCLUSIONS.

1. A typical peptone shock is obtained by the injection of a histamine-free peptone; hence peptone shock and histamine shock are not identical.

2. A histamine-free peptone contracts the excised virgin guinea pig uterus.

3. Pure peptone contains a substance or substances, apparently basic in character, that are not destroyed by boiling with hydrochloric acid, that are precipitated by phosphotungstic acid, extracted by amyl alcohol from an alkaline aqueous solution, that combine with sulfuric acid to give salts that are soluble in water, and that are capable of producing a fall in blood pressure. This fall in blood pressure is, however, far inferior to the similar fall in blood pressure obtained with the equivalent quantity of peptone. In the above respects the substances are similar to histamine. There are, however, two very marked differences between the above substances and histamine; they give no color with *p*-phenyldiazonium sulfonate and they do not contract the excised virgin guinea pig uterus.

4. A sample of Witte's peptone—100 gm.—was found to contain the equivalent of 0.00335 gm. of histamine dichloride.

STUDIES ON PROTEINOGENOUS AMINES.

XI. RESPONSE OF THE EXCISED UTERUS TO POTASSIUM, RUBIDIUM, AND CESIUM IONS.

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While we were searching for histamine in feces, blood, liver, and hypophysis, we noticed that the silver filtrate fractions,¹ although they could not have contained more than traces of histamine, frequently evoked a pronounced response from the excised virgin guinea pig uterus. Since this fraction always contains a small quantity of the nitrate ion, which is originally introduced as silver nitrate, we thought, at first, that this ion might be responsible for the physiological activity. To test the accuracy of this surmise, 1 cc. each of chemically pure 10 per cent solutions of sodium and potassium nitrate were separately introduced into the 100 cc. of Locke-Ringer solution in which the uterus was suspended. Fig. 1 illustrates the response obtained with the potassium nitrate solution. *A response was not obtained with the sodium nitrate solution.* From these results we concluded that the sodium and the nitrate ions did not stimulate the uterus muscle and that the response obtained with potassium nitrate was due to the potassium ion. This led naturally to an investigation of the effect of some of the other closely related metallic ions on the excised uterus.

Solutions of chemically pure sodium chloride, sodium nitrate, lithium chloride, ammonium chloride, potassium chloride, potassium nitrate, rubidium chloride, cesium chloride, calcium chloride, and magnesium sulfate were employed in these tests. *A response was obtained only with the potassium, rubidium, and*

¹Hanke, M. T., and Koessler, K. K., *J. Biol. Chem.*, 1920, xliii, 547.



FIG. 1. Response of the excised virgin guinea pig uterus to potassium nitrate. The uterus was suspended in 100 cc. of a Locke-Ringer solution.



FIG. 2. Response of the excised virgin guinea pig uterus to various concentrations of potassium chloride. The uterus was suspended in 100 cc. of a Locke-Ringer solution.



FIG. 3. The response of the excised virgin guinea pig uterus to various concentrations of rubidium chloride. The uterus was suspended in 100 cc. of a Locke-Ringer solution.



FIG. 4. Response of the excised virgin guinea pig uterus to various concentrations of cesium chloride. The uterus was suspended in 100 cc. of a Locke-Ringer solution. The first curve, a typical histamine tracing, is introduced for the sake of comparison.

cesium salts. Fig. 2 shows the response obtained when 0.20, 0.30, 0.50, and 1.0 cc. of a 10 per cent solution of potassium chloride were introduced into the 100 cc. of Locke-Ringer solution in which the uterus was suspended. Fig. 3 illustrates the response obtained when 0.05, 0.10, 0.40, 0.80, and 1.6 cc. of a 10 per cent solution of rubidium chloride were introduced into the 100 cc. of Locke-Ringer solution in which the uterus was suspended. The last two tracings in this figure illustrate the response evoked by equivalent quantities of potassium and rubidium salts. Fig. 4 shows the response obtained when 1.0, 1.5, and 2.2 cc. of a 10 per cent solution of cesium chloride were introduced into the 100 cc. of Locke-Ringer solution. The first tracing in this figure was obtained by introducing 0.50 cc. of a 0.01 per cent solution of histamine dichloride into the 100 cc. of Locke-Ringer solution and it is inserted here merely for comparison.

Since no response was obtained with equivalent quantities of sodium chloride, sodium nitrate, ammonium chloride, lithium chloride, calcium chloride, and magnesium sulfate it is safe to say that the Cl, NO₃, SO₄, NH₄, Li, Ca, and Mg ions have no stimulating action upon the uterus muscle and that the potassium, rubidium, and cesium ions are responsible for the response obtained.

CONCLUSIONS.

Potassium and rubidium salts in sufficient concentration—about $N/75$ in each case—produce a tonic contraction of the virgin guinea pig uterus from which the muscle does not recover until the stimulating ions are removed. The minimum effective concentration of the potassium ion is $N/150$ and of the rubidium ion is $N/1,210$ from which it appears that the rubidium is approximately eight times as active as potassium. The minimum effective concentration of cesium appears to be about $N/150$; but the response obtained with this ion is neither so vigorous nor so permanent as that obtained with either potassium or rubidium.

SOME NUTRITIVE PROPERTIES OF NUTS; THEIR PROTEINS AND CONTENT OF WATER- SOLUBLE VITAMINE.*

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(Received for publication, June 25, 1920)

The extensive series of metabolism experiments on fruitarians and nutarians in California reported by Jaffa (1901, 1903) indicated that nuts used as a substantial component of the diet are quite thoroughly digested and are of a higher nutritive value than is popularly attributed to them. The same conclusion was reached by Cajori (1918) through digestion trials of raw and heated nuts, nut butters, and nut pastes. In his experiments the coefficient of digestibility for nut proteins and carbohydrates fell well within the range of the protein coefficient for a mixed diet. There was no indication that nuts are especially resistant to the digestive functions of the alimentary canal; so that the conclusion seemed justified that nuts are valuable foods and, if eaten properly and used in the diet with due regard to their concentrated make-up, are on a physiological par with common staple articles of the diet. A more detailed investigation of the nutritive properties of nuts has, however, hitherto been wanting.

The Nutritive Value of Nut Proteins.

It is clearly recognized that individual proteins may vary greatly in the proportions of the various amino-acids which may be obtained from them and that their dietary value depends in

* The data in this paper are taken from the dissertation presented by the writer for the degree of Doctor of Philosophy, Yale University, 1920. A part of the expense of the investigation was defrayed by a grant from the Russell H. Chittenden Research Fund for Physiological Chemistry.

large part on the character of this amino-acid yield. An appreciation of the significance of these nutritive differences is largely due to the extended studies of Osborne and Mendel and others, who have demonstrated in the case of the albino rat that the naturally occurring proteins differ widely in their efficiency for maintenance or growth.

With reference to *the chemical make-up of the proteins of nuts*, Osborne and Clapp (1907, 1907-08) have studied the products of acid hydrolysis of amandin and excelsin, the principal proteins of the almond and Brazil nut, respectively. Osborne and Harris (1903, *a, c, d*) compared the distribution of basic amino-acid nitrogen in the globulins of the almond, Brazil nut, black walnut, English walnut, butternut, and filbert, and have shown that the Hopkins-Cole test for tryptophane is strongly positive with all these proteins. From the investigations of these authors, the black walnut, English walnut, and butternut would seem to contain very similar, if not identical, globulins as their principal proteins. The name juglansin has been given to this globulin of the *juglans* species of nut. Osborne and Harris (1903, *b*) found the only essential difference between corylin, the globulin from the filbert or hazel nut, and juglansin to be a higher content of amide nitrogen in corylin and a difference in the specific rotation of the two proteins. Using Van Slyke's newer method for protein analysis, Nollau (1915) has analyzed the pecan nut, peanut, black walnut, and hickory; Johns and his collaborators (1917, 1919, *a*) applied the same method to a study of the globulins of the peanut and coconut. In all these studies, the relatively high content of basic amino-acids found and the presence of tryptophane suggest that these nuts are likely to be sources of complete protein. Speaking of the peanut, Johns says: "the relative high percentage of lysine in the proteins of the peanut indicates that this seed might be used to advantage in supplementing diets deficient in lysine."

This conclusion, based on chemical analysis, that nut proteins are of a high biological value, has been verified by the feeding experiments of Johns and coworkers (1919, *b*) with the coconut, and Daniels and Loughlin (1918) with the peanut. These investigators observed normal growth in young rats on diets in which the coconut and peanut furnished the sole source of protein. Osborne and Mendel (1912) have maintained rats over long periods in which the protein of the dietary was derived from excelsin of the Brazil nut.

Feeding Experiments with Rats.

The experience of numerous investigators in experiments involving growth and maintenance has demonstrated the many advantages in the use of the rat as an experimental animal in nutrition studies.

Following the general technique of Osborne and Mendel, as recently described by Ferry (1920), we have extended the feeding observations on nuts to include the almond, English walnut, filbert, pecan, and pine nut. Young rats were fed on diets complete in respect to every known dietary essential for growth, provided the proteins were of a character to support growth. Nut proteins made up approximately 18 per cent of the diets. It is well recognized that rats will grow to adult size at a normal rate on this level of protein intake, if the protein is "complete" from a nutritive point of view; i.e., furnishes all the essential amino-acids in suitable amounts.

There are not many nuts that contain over 3 per cent of nitrogen. Therefore in order to prepare a diet containing 18 per cent of protein (e.g. 2.9 per cent N \times 6.25) and still insure, in addition to the protein, the presence of adequate quantities of the recognized dietary essentials, fat-soluble and water-soluble vitamins and inorganic salts, concentration of the protein of certain of the nuts was necessary. To effect this, the shelled nuts were passed through a meat grinder and then subjected to pressure in a tincture press. This process removed considerable quantities of oil from the nut, and nitrogen determinations of the residual press cake indicated that the protein content had been sufficiently increased to incorporate in the diet at the desired 18 per cent protein level.

Charts 1 and 2 show the growth curves of albino rats on diets in which the essential source of protein was derived from nuts. At the time these experiments were inaugurated the presence of water-soluble vitamins in the nuts used had not been demonstrated. Dried brewer's yeast was added to the diets, to the extent of 2 per cent, to make sure that they contained adequate quantities of this dietary essential. The possibility of the supplementary action of the yeast in these diets must be recognized. Osborne and Mendel (1919, a) found yeast to be adequate for growth when fed as the sole source of protein. However, the amount of protein derived from yeast fed in a concentration of 2 per cent and its supplementing action cannot be large. In Osborne and Mendel's successful experiments the dried yeast furnished 30 and 40 per cent of the total food intake. Neuberg (1916) estimates that 52 per cent of yeast nitrogen is non-protein

TABLE I.
Weekly Food Consumption on Nut Diets.

Week.	Almond.	English walnut.	Filbert.	Pecan.		Pine nut.		Casein.	
	Average for Rats 10, 11, 12.	Average for Rats 13, 14, 15.	Average for Rats 16, 17.	Rat 30.	Rat 31	Rat 32.	Rat 33.	Rat 7.	Rat 8.
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.
1	45	50	40	43	40	39	42	41	41
2	41	40	40	60	40	45	42	44	42
3	33	42	39	48	35	39	38	53	48
4	42	47	44	46	34	35	44	50	52
5	44	51	44	47	41	53	50	54	54
6	50	45	41	47	33	44	37	61	59
7	55	50	54	44	40	48	43	59	57
8	49	50	41	43	41	44	48	61	63
9	51	48	58	44	40	53	57	63	54
10	53	48	45	55	59	57	52	54	47
11	51	48	54	52	50	59	46	61	58
12	51	46	56	52	51	53	55		
13	50	47	45	54	47	45	50		
14	52	42	38			46	52		
15	56	43	53			45	45		
16	66	43	53			48	55		
17	57	41	50			54	50		
18	48	38	41			63	62		
	Rat 10.	Rat 12 + young.	Rat 16 + young.	Rat 17.					
19	65	68	37	41		65	66		
20	50	76	69	31		65	55		
21	49	60	69	41		60	50		
22	49	49	60	40		68	59		
23	45	49	65	41		65	53		
24	61	61	85	42		63	54		
25	54	62	98			77	45		
26		84	91			80			
27		104	46*			99			
28		122	42						
29		117							
30		45*							
31		44							

* Young removed.

nitrogen. If this estimation is correct, yeast proteins made up but 4 per cent of the total protein of our diets.

Table I gives the weekly food consumption of the rats on the nut diets. The average normal intakes of animals of *the same weight* on a comparable casein diet are on record (Osborne and Mendel, 1915). The animals, as a rule, ate less of the nut food than did Osborne and Mendel's rats on the casein diet similar in composition to that from which their normal intake was calculated. The nut foods, consisting of a large quantity of a fat-rich press cake probably were of a higher calorific value than the casein diet. This fact would explain these differences, as the quantity of food eaten by rats which limit their intake to their energy requirement is largely determined by the calorific value of the food.

Examination of the growth curves shows that growth resulted at a normal rate on all diets except the one in which the pecan supplied the protein. The animals on this diet grew at a rate about two-thirds normal during the 9 weeks that they were on this diet. When casein was introduced into the pecan diet in such a way that one-third of the pecan protein was replaced by casein, a marked rise in the rate of growth was noted. This increased growth may have been due either to a supplementing action of the casein or to an increased food intake resulting from some favorable modification in the taste or character of the pecan diet on addition of casein.

More experiments are necessary before final conclusions can be drawn regarding the comparative efficiency of the proteins of the pecan.

Growth of the second generation of young rats on the nut diets is shown in Chart 3.

With the limited number of observations that we have recorded it is not possible to make numerical comparisons of different nut proteins, nor were our experiments planned to demonstrate the maximum growth-promoting power of nut proteins. But, accepting the opinion of Osborne and Mendel (1920, *a*), ". . . that if an animal is able to attain adult size upon a diet which furnishes protein from a single source, the nutritive value of this protein is clearly established," we conclude from our experiments that the almond, English walnut, filbert, and pine nut are sources of protein adequate for nutrition.

Nuts as Sources of Water-Soluble Vitamine.

Numerous feeding experiments, carried out during the last few years, have demonstrated that vitamin_{es} are widely distributed among plant products. The cereals, vegetables, and forage crops have been investigated in some detail as to their content of the water-soluble and fat-soluble vitamin_e. Nuts, as a class, however, have received little attention with respect to the presence in them of these important dietary essentials.

Halliburton and Drummond (1917), studying various naturally occurring fats, failed to obtain normal growth in rats when the butter of their diets was replaced by coconut oil, peanut oil, or walnut butter. Hence the fat-soluble vitamin_e would seem to be absent in nut oils. Daniels and Loughlin (1918) showed that peanuts are lacking in the fat-soluble factor but that considerable amounts of the water-soluble vitamin_e are present; and Johns, Finks, and Paul (1919) observed satisfactory growth in young rats on diets in which coconut meal was supplemented by butter and inorganic salts only and therefore represented the sole source of water-soluble vitamin_e. Mackenzie-Wallis (1918) has reported that a flour made from ground peanuts was antiscorbutic. Grieg (1918) used ground nut meal biscuits with some success as a therapeutic agent in experimental beri-beri.

Feeding Experiments with Rats.

We have studied many of the more common nuts, that have not previously received attention, as possible sources of water-soluble vitamin_e and have planned our experiments with a view to being able to obtain an approximate quantitative idea of the comparative distribution of this essential food factor among members of this class of plant products.

Two methods are available for such trials. An animal may be placed on a diet deficient in respect to the water-soluble factor. On such a diet, the animal, if it is still small, will cease to grow and in any event will, in a short time, begin to decline rapidly in weight, a condition that terminates in death unless a change is made in the diet. If a product containing sufficient quantities of water-soluble vitamin_e is added to the diet before the animal is permanently injured by undernourishment, a rapid recovery of weight and nutritive well-being take place. The second method depends on the fact that normal growth can be observed in young rats only when the product to be tested is available in sufficient

quantities to supplement an otherwise complete diet with an abundance of water-soluble vitamine.

In the experiments reported below, both methods were employed. The basal diet used, consisting of casein, butter fat, inorganic salts, starch, and lard, was deficient in water-soluble vitamine as evidenced by the rapid decline of animals when placed on this food mixture exclusively. Control experiments indicated that the casein diet was complete with respect to all other food essentials, as normal growth was observed when small amounts of brewer's yeast, known to be rich in water-soluble vitamine, were added to this diet.

In the majority of our trials weighed quantities of the nut to be tested were fed daily apart from and in addition to the basal diet. This method, introduced by Osborne and Mendel (1919, b), insures a constant intake of the product under investigation and enables a comparison to be made of the potency of the foods consumed in like amounts. By varying the daily dosage, further evidence in respect to the comparative quantities of the water-soluble vitamine present can be obtained.

The nuts were shelled and care was taken to remove all fragments of the shell and the coarser parts of the integument. In the case of the almond, the nut was blanched. The chestnuts used in the later trials (Charts 6 and 8) were fed after completely freeing them from the adhering integument. We found that the rats, at least after the first few days, readily ate the nuts and, as a rule, consumed the entire nut allowance as soon as it was placed in the cage. The only failure to eat that we experienced was in the case of the Brazil nut. It was found necessary to incorporate this nut in the basal diet before the animals would consume it in the desired amounts.

The outcome of the restorative trials is shown in Charts 4, 5, and 6 and Table II. A daily dosage of 2 gm. of hickory nut, pine nut, and pecan, respectively, or the inclusion of 27 per cent of almond, or filbert, and 19 per cent of English walnut in the food sufficed to enable animals that had declined on the basal diet to recover rapidly their nutritional well-being and resume growth. 1 gm. of English walnut, black walnut, hickory nut, or pine nut proved to be an equally efficient restorative agent. Partial recovery and slow growth resulted from daily consump-

tion of 1 gm. of almond and 0.5 gm. of chestnut, English walnut, or pecan in addition to the basal diet. These charts show that all the nuts tested are comparatively rich in water-soluble vitamine. The chestnut, English walnut, and pecan appear to be especially potent, daily doses of 0.5 gm. sufficing to permit slow growth. The animals receiving 1 gm. daily of either

TABLE II.
Weekly Consumption of Basal Diet and Nuts.

Week.	Hickory nut.				Pine nut.				Almond.			
	Rat 4.	Rat 6.	Rat 38.	Rat 39.	Rat 8.	Rat 9.	Rat 34.	Rat 35.	Rat 2.	Rat 18.	Rat 19.	Rat 20.
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.
1	53	80	43	43	58	49	22	46	71	43	47	48
2	52	68	32	37	55	45	13	37	63	41	41	36
3	42	65	49	29	56	44	31	53	55	43	39	39
4	59	58	61	36	45	37	74	78	32	45	48	46
5	49	61	62	58	31	29	78	60	65	25	38	29
6	80	101	63	55	46	32	73	55	72	27	27	22
7	62	82			79	58			69	44	42	41
8	62	78			59	58			71	43	49	36
9	58	73			60	63			59	43	51	40
10	68	78			60	58				30	40	40
11										56	42	51
12										54	56	56
13												
	English walnut.					Pecan nut.						
	Rat 3.	Rat 7.	Rat 24.	Rat 30.	Rat 31.	Rat 21.	Rat 22.	Rat 25.	Rat 26.			
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.			
1	74	61	47	52	45	51	38	54	39			
2	59	53	52	57	53	49	41	70	50			
3	46	49	42	52	37	42	32	64	50			
4	32	42	38	36	22	34	24	53	44			
5	88	30	35	35	28	61	46	32	29			
6	71	30	67	53	30	59	42	23	24			
7	55	23	68	57	31	45	31	47	40			
8	55	60	61	58	48	58	37	50	49			
9	67	57		53	57	54	35	54	42			
10	77	73		59	63	60	35	44	44			
11		59		73	51			52	62			
12		53		53	48			59	69			
13								60	60			

TABLE II—*Concluded.*

Week.	Chestnut.			Black walnut.		Filbert.
	Rat 27.	Rat 28.	Rat 29.	Rat 36.	Rat 37.	Rat 1
	gm.	gm.	gm.	gm.	gm.	gm.
1	66	55	62	50	47	84
2	55	56	63	39	34	57
3	32	50	32	31	44	45
4	21	30	27	45	19	36
5	19	19	26	48	35	112
6	43	43	50	52	45	106
7	51	38	47	63	44	80
8	43	34	43			82
9	41	37	44			
10	45	39	45			
11	55	45	56			
12	55	50	59			
13	58	65	67			

English walnut or pine nut showed as rapid recovery as in any trial where the daily dose of other nuts was 2 gm. A comparison of the growth curves indicates that the almond was not so efficient as a source of water-soluble vitamine. 1 gm. of this nut was less effective as a restorative agent than 0.5 gm. of the pecan or chestnut.

Osborne and Mendel (1920, *b*) believe that animals which have suffered a decline due to a deficiency of water-soluble vitamine may become so badly nourished that failure to effect prompt resumption of growth may sometimes be ascribed to the condition attained by the animal rather than to a lack of the vitamine in the tested product used as a supplement to the deficient diet. The rats used in our experiments were subjected to quite similar degrees of undernutrition and it would seem that the variations in rapidity of recovery can be interpreted, in our experiments, as being due to differences in the quantity of water-soluble vitamine present in different nuts rather than to a radical difference in the nutritive condition of the animals at the time that the nut feeding was inaugurated. The weekly food intakes are shown in Table II.

The growth curves of animals on diets in which nuts, supplied in different daily doses, furnished the sole source of water-soluble

vitamine are shown in Charts 7 and 8. Here again, the richness of nuts in this vitamine is demonstrated. Normal growth was observed when the basal diet was supplemented daily by 2 gm.

TABLE III.
Weekly Consumption of Basal Diet and Nuts.

Week.	Almond.			English walnut.			Brazil nut.			Black walnut.	
	Rat 18.	Rat 19.	Rat 20.	Rat 21.	Rat 22.	Rat 23.	Rat 24.	Rat 25.	Rat 26.	Rat 34.	Rat 35.
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.
1	44	43	43	48	47	41	48	50	43	77	55
2	42	43	42	43	42	39	46	47	48	68	67
3	47	43	43	43	39	38	48	31	34	71	55
4	46	43	47	47	44	37	46	45	33	70	60
5	40	41	47	51	38	40	43	38	43	54	55
6	39	37	41	51	35	40	43	38	35	46	64
7	44			61	42	43		58		37	54
8	42			45	35	43		52		40	50
9				51	36	47		54		34	43
10										31	62
11										30	64
Chestnut.						Pecan.		Yeast.			
	Rat 27.	Rat 28.	Rat 29.	Rat 38.	Rat 39.	Rat 36.	Rat 37.	Rat 9.			
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.			
1	53	47	50	60	70	66	73	41			
2	51	51	50	57	57	56	55	41			
3	51	44	51	54	57	55	54	45			
4	52	45	53	47	63	48	66	47			
5	51	52	68	52	61	52	62	43			
6	42	45	45	60	61	54	55	39			
7	60	53	57	55	59	55	57	49			
8	56	48	55	55	54	51	59	50			
9	66	55	62	47	51	57	46	56			
10				51	48	58	47				
11				48	55	49	55				

of the almond, English walnut, chestnut, Brazil nut, or black walnut. When the daily ration of the nut was 1 gm., the pecan and chestnut furnished sufficient quantities of this dietary factor for normal growth.

The weekly food intakes are shown in Table III. The characteristic decline in food consumption during the period when there was insufficient water-soluble vitamins in the food, and the prompt recovery of appetite and resumption of eating when the vitamins were added to the diet, are to be noted.

Nut Proteins and Milk Production.

The present experiments with nut diets have furnished an opportunity to test some of the relations of the dietary proteins to milk production, inasmuch as a number of the female rats under observation were bred in the course of the feeding trials. If the mammary gland has at best a limited power, if any, of synthesizing the essential amino-acid precursors of its protein complexes (McCollum and Simmonds, 1918), the importance of furnishing a proper source of amino-acid groups in the ration during lactation is evident.

In studying the lactation of dairy cows, Hart and Humphrey (1915, 1916, 1917, 1918), among others have found wide differences in the efficiencies of various protein mixtures as producers of milk. Not only the quantity but also the biological quality of the proteins in the ration affect the character of the mammary secretion. Likewise Hoobler (1917, *a, b*) has concluded from studies of wet nurses that, as a rule, animal proteins are more efficient than vegetable proteins for the elaboration of human milk. However, nut proteins were an exception to this generalization in that diets containing almonds, English walnuts, pecans, and peanut butter as a source of protein proved to be as suitable for milk production as diets which furnished protein from animal sources. In other words, nuts seemed to furnish the nitrogenous complexes necessary for the elaboration of milk as effectively as any other type of protein.

Judging the character of milk production by the ability of the mother to nurse her young successfully, we have observed satisfactory mammary function in rats, on diets containing the almond, English walnut, pine nut, and filbert as the essential source of protein in the ration. Some loss of weight of the mother rat occurred during the nursing period in the experiments with the almond, English walnut, and filbert, but tissue disintegration during the temporary decline could scarcely have furnished enough indispensable nutrient units to account for the newly synthesized milk protein sufficient in quantity to have produced the increments in weight observed in all the young.

SUMMARY AND CONCLUSIONS.

Satisfactory growth was observed in young rats on diets in which the almond, English walnut, filbert, and pine nut, respectively, furnished the essential source of protein in the ration.

Normal growth can be secured when rats are fed upon otherwise adequate diets containing the almond, English walnut, black walnut, Brazil nut, chestnut, or pecan as the sole source of water-soluble vitamine. Animals which have declined on a diet devoid of water-soluble vitamine promptly recover when the almond, English walnut, filbert, hickory, pine nut, chestnut, or pecan is introduced in the diet. These observations indicate that nuts are sources of abundant quantities of water-soluble vitamine.

The proteins of the almond, English walnut, pine nut or filbert furnish the necessary nitrogenous complexes for the elaboration of milk in rats.

I desire to express my hearty thanks to Professor Lafayette B. Mendel, who suggested this study to me, for his helpful advice and criticism during the course of the investigation.

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CHART 1. Growth of young rats on diets in which the English walnut, pine nut, and pecan, incorporated in the diet in the form of a press cake, furnished the essential source of protein. A casein diet of similar composition, except for protein, served as a control experiment. The broken line in the curves of Rats 30 and 31 indicate the period when the pecan diet was replaced by a mixture of one part casein diet and two parts pecan diet.

The composition of the casein and nut diets was as follows:

Casein Diet.

Rat 7.	per cent
Casein.....	18
Salt mixture*.....	4.5
Starch.....	50.5
Butter fat.....	9
Lard.....	18
Brewer's yeast, dried.....	200 mg. daily.

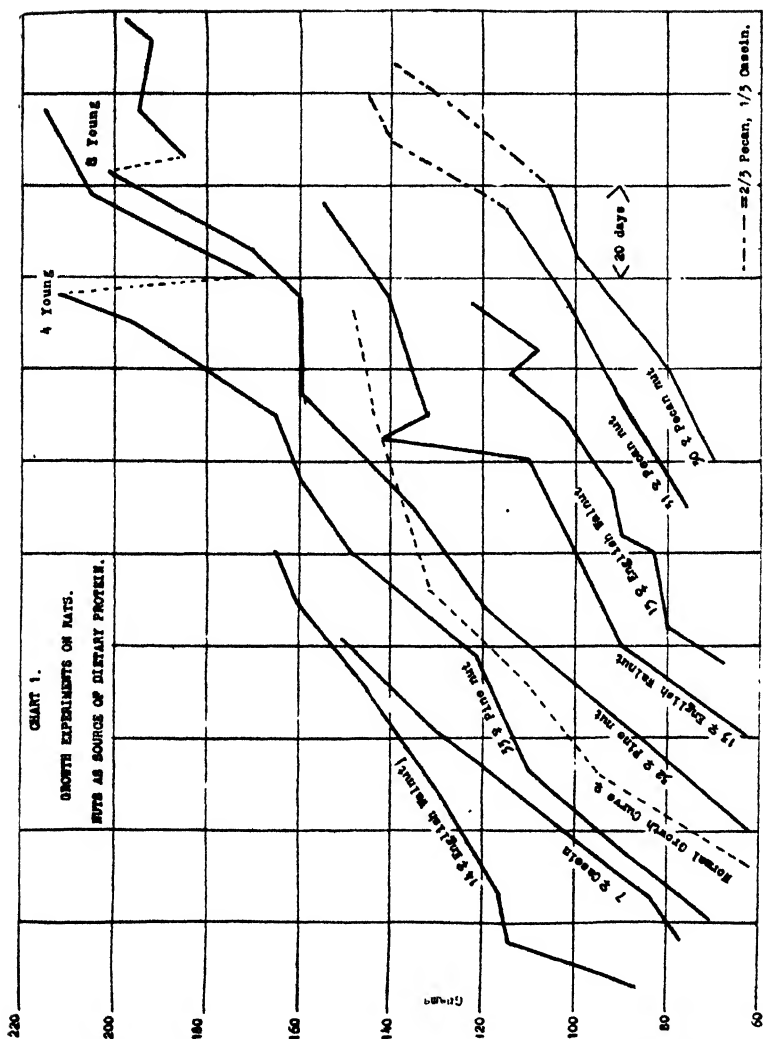
* The salt mixture used in all the diets of the feeding trials is that described by Osborne, T. B., and Mendel, L. B., *J. Biol. Chem.*, 1917, xxxii, 317.

English Walnut Diet.

Rats 13, 14, 15.	per cent
English walnut press cake, 3.5 per cent N.....	82
Salt mixture.....	3
Starch.....	4
Butter fat.....	5
Lard.....	4
Brewer's yeast, dried.....	2

Pine Nut Diet.

Rats 32, 33	per cent
Pine nut.....	50
Salt mixture.....	3
Starch.....	36
Butter fat.....	5
Lard.....	6
Brewer's yeast, dried.....	200 mg. daily.



Pecan Diet.

	per cent
Pecan press cake, 3.6 per cent N.....	80
Salt mixture.....	3
Starch.....	7
Butter fat.....	5
Lard.....	5
Brewer's yeast, dried.....	200 mg. daily.

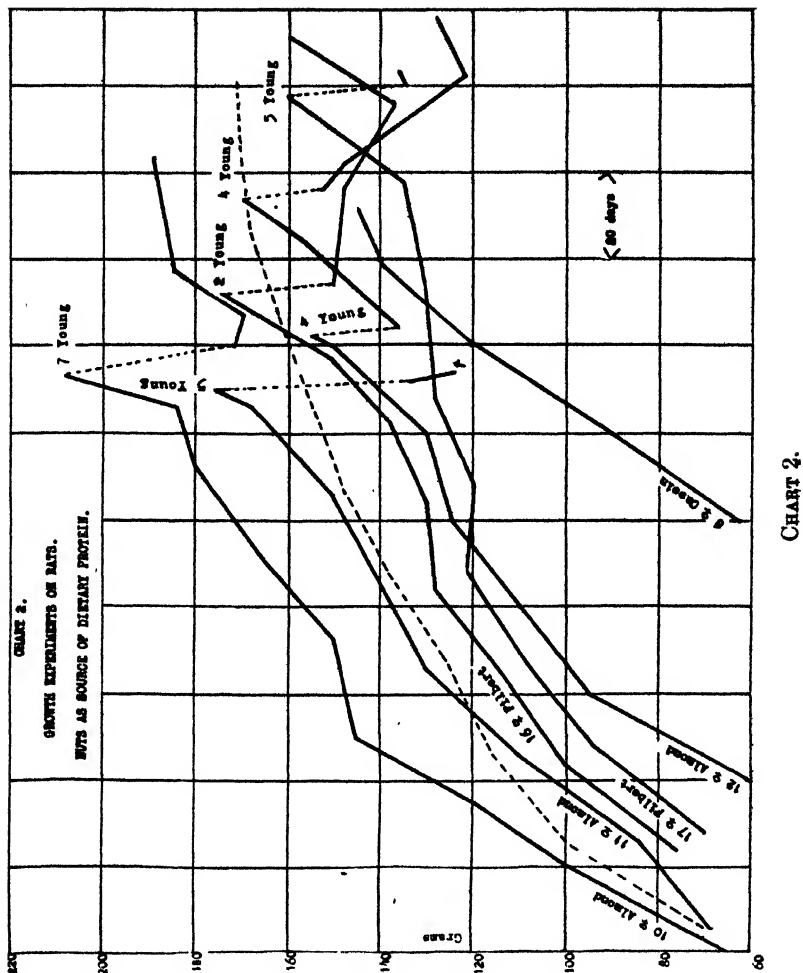


CHART 2. Growth of young rats on diets where the almond and filbert, incorporated in the diet in the form of a press cake, furnished the essential source of protein.

The composition of the casein diet was the same as given in the description of Chart 1. The composition of the nut diets was as follows:

Almond Diet.

Rats 10, 11, 12.

	per cent
Almond press cake, 5.0 per cent N.....	58
Salt mixture.....	3
Starch.....	12
Butter fat.....	5
Lard.....	20
Brewer's yeast, dried.....	2

Filbert Diet.

Rats 16, 17.

	per cent
Filbert press cake, 3.6 per cent N.....	80
Salt mixture.....	3
Starch.....	3
Butter fat.....	5
Lard.....	7
Brewer's yeast, dried.....	2

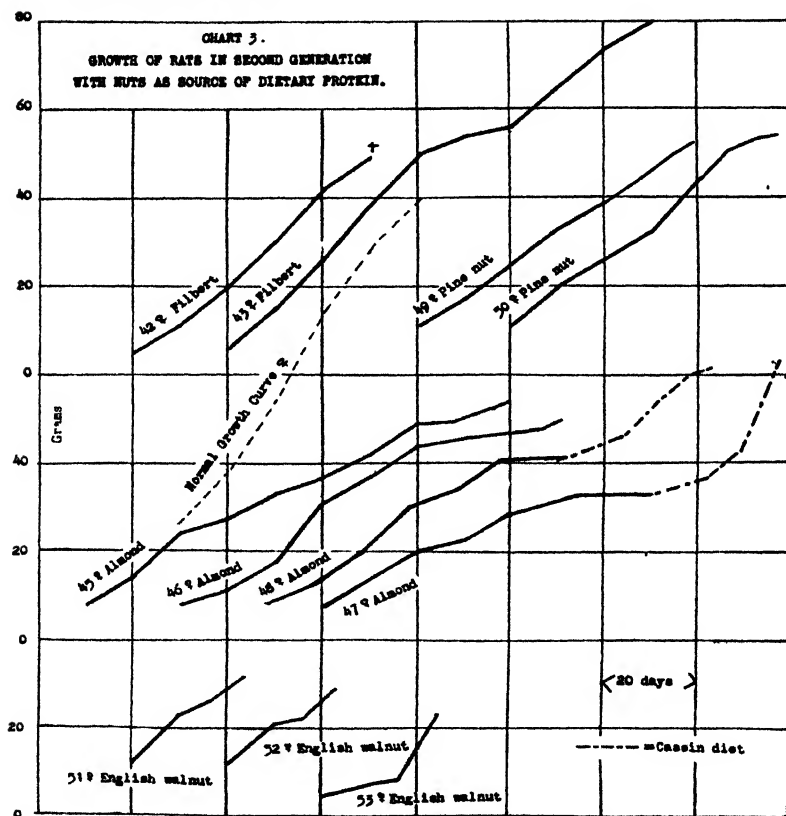


CHART 3. Growth of the second generation of young rats on diets in which almond, English walnut, filbert, and pine nut, incorporated in the diet in the form of a press cake, furnished the essential source of protein. The broken line in the curves of Rats 47 and 48 indicates the period when the almond diet was replaced by the casein diet and 100 mg. of dried yeast daily.

The composition of the casein and nut diets was the same as described in Charts 1 and 2.

CHART 4. Recovery of growth of animals which had declined on a diet devoid of water-soluble vitamins, on the addition of the almond, filbert, hickory nut, pine nut, pecan, and English walnut as supplements to the basal diet.

The animals receiving the hickory nut, pine nut, and pecan were given 2 gm. of the nut daily.

The almond, filbert, and English walnut, respectively, were incorporated in the diet, one part of nut diet and two parts of basal being thoroughly mixed together. In such a mixture the almond and filbert nut furnished 27 per cent of the diet and the English walnut 19 per cent.

The broken line on the curves denotes the period when the animals were on the basal diet.

The composition of the diets was as follows:

Basal Diet.

	<i>per cent</i>
Casein.....	18
Salt mixture.....	4.5
Starch.....	50.5
Butter fat.....	9
Lard.....	18

Almond Nut Diet.

<i>Rat 2.</i>	<i>per cent</i>
Almond press cake.....	58
Salt mixture.....	3
Starch.....	14
Butter fat.....	5
Lard.....	20

Filbert Diet.

<i>Rat 1.</i>	<i>per cent</i>
Filbert press cake.....	80
Salt mixture.....	3
Starch.....	5
Butter fat.....	5
Lard.....	7

English Walnut Diet.

<i>Rat 3.</i>	<i>per cent</i>
English walnut press cake.....	82
Salt mixture.....	3
Starch.....	6
Butter fat.....	5
Lard.....	4

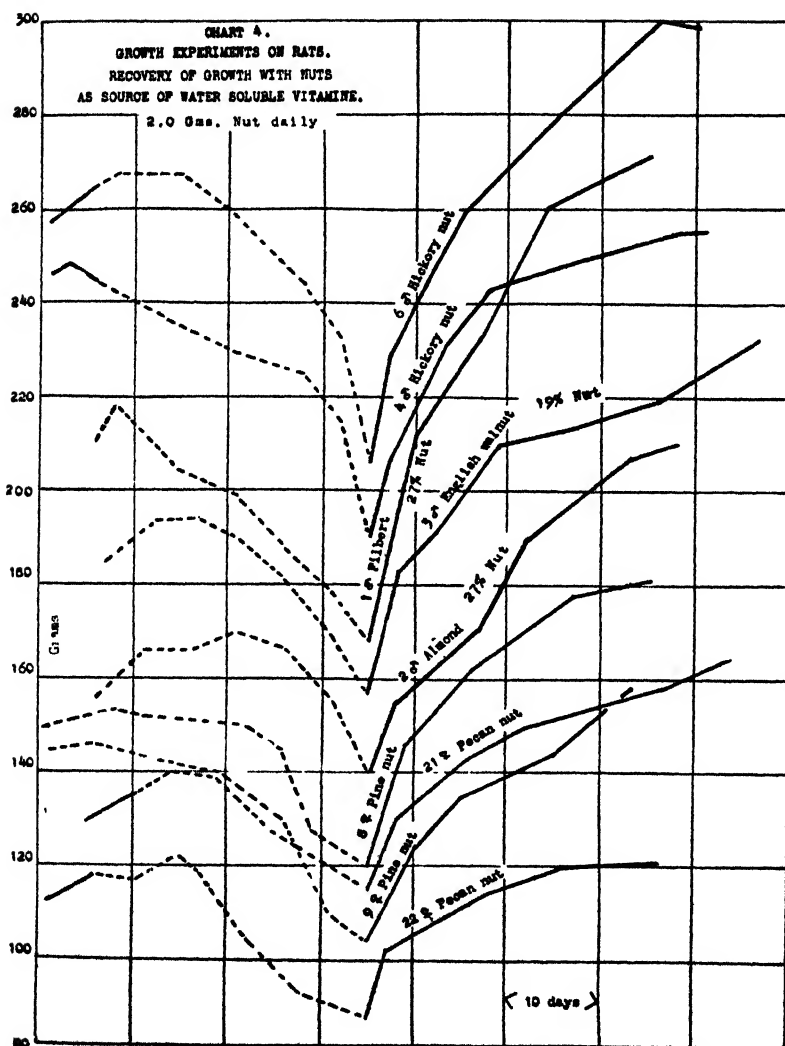


CHART 4.

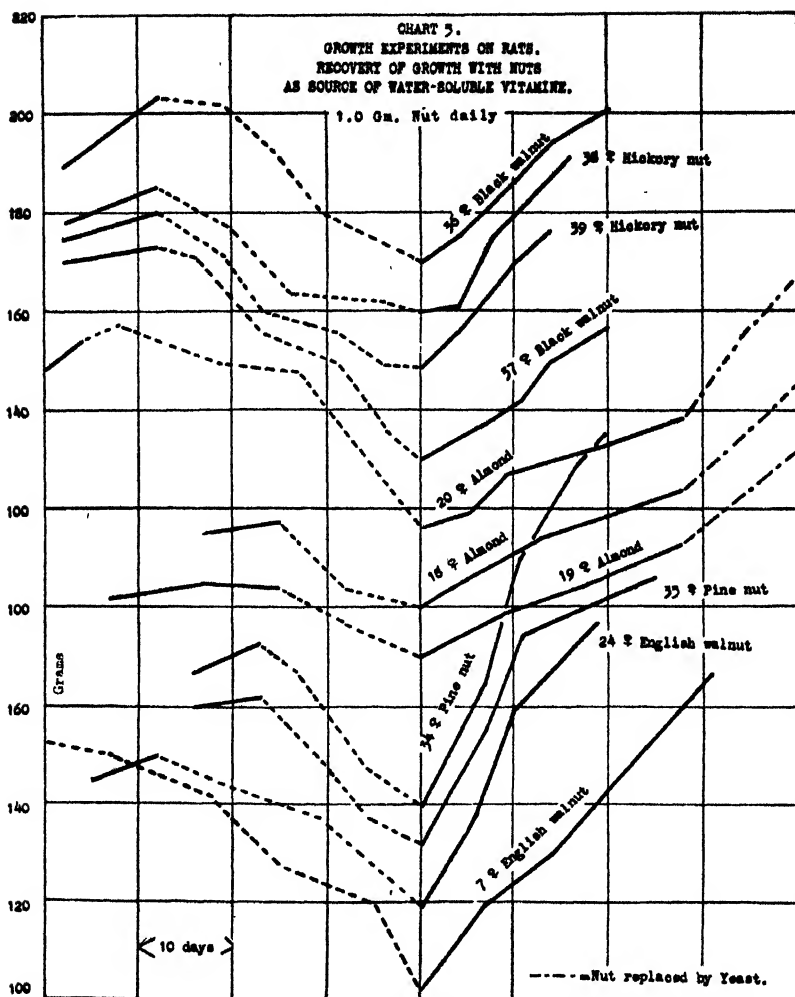


CHART 5. Recovery of growth of animals which had declined on a diet devoid of water-soluble vitamine, on the addition of almond, hickory nut, black walnut, pine nut, and English walnut as supplements to the basal diet.

The animals were given 1 gm. of nut daily.

The broken line of the curves denotes the period that the animals were on the basal diet.

The composition of the basal diet was the same as described in Chart 4.

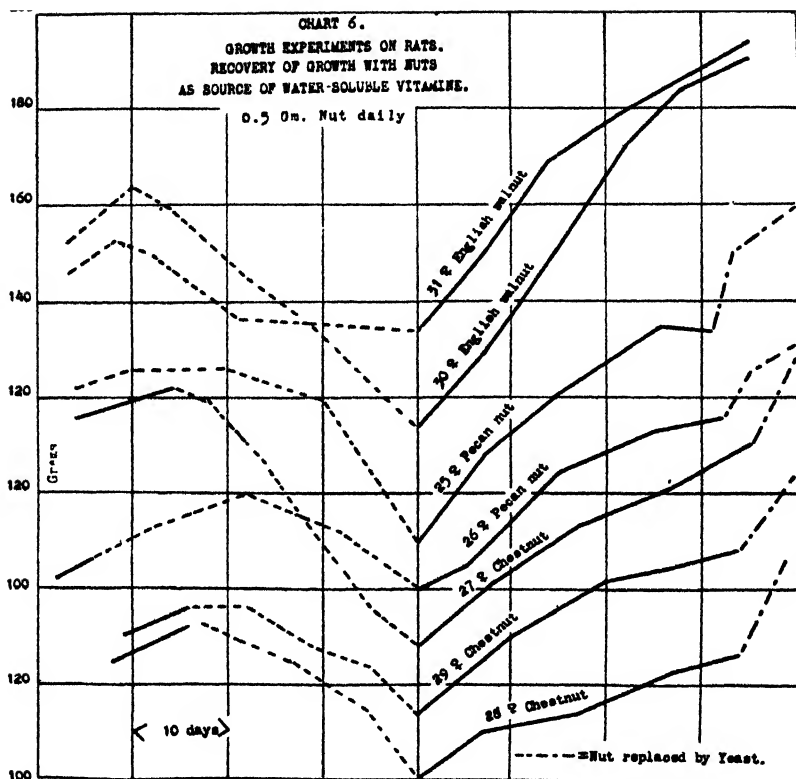


CHART 6. Recovery of growth of animals which had declined on a diet devoid of water-soluble vitamine, on the addition of the English walnut, chestnut, and pecan as supplements to the basal diet.

The animals were given 0.5 gm. of nut daily.

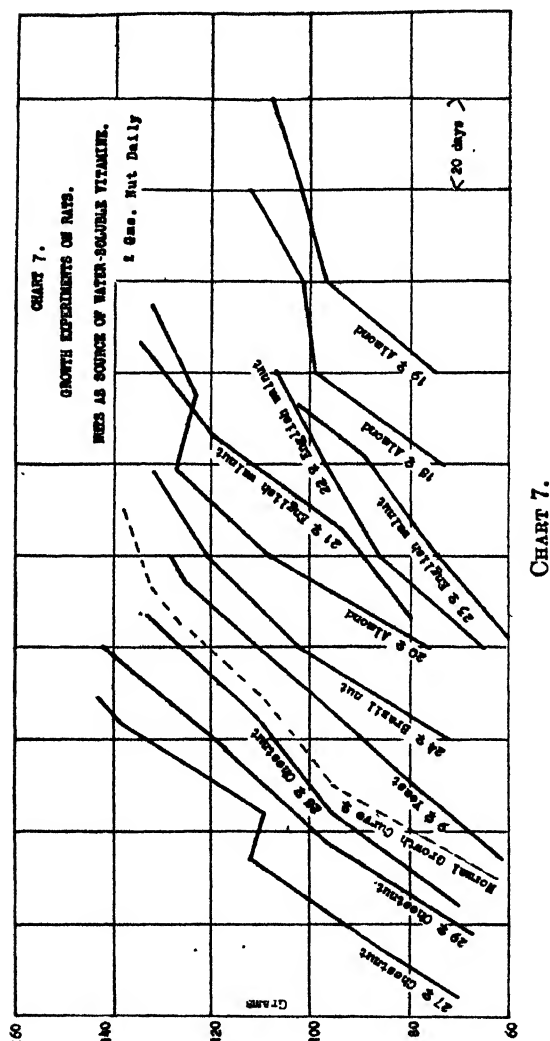
The chestnut was blanched before feeding.

The broken line indicates the period that the animals were on the basal diet alone.

The composition of the basal diet was the same as described in Chart 4.

CHART 7. Growth of young rats on diets where the almond, English walnut, chestnut, and Brazil nut furnish the sole source of water-soluble vitamine. 2 gm. of the nut were fed daily in addition to the basal diet. The basal diet was found to be inadequate to support growth unless supplemented by a source of water-soluble vitamine (see Charts 4, 5, 6).

The almond was blanched before feeding. The coarser parts of the integument of the other nuts were removed.



The composition of the basal diet was as follows:

Basal Diet.

	per cent
Casein.....	18
Salt mixture.....	4.5
Starch.....	50.5
Butter fat.....	9
Lard.....	18

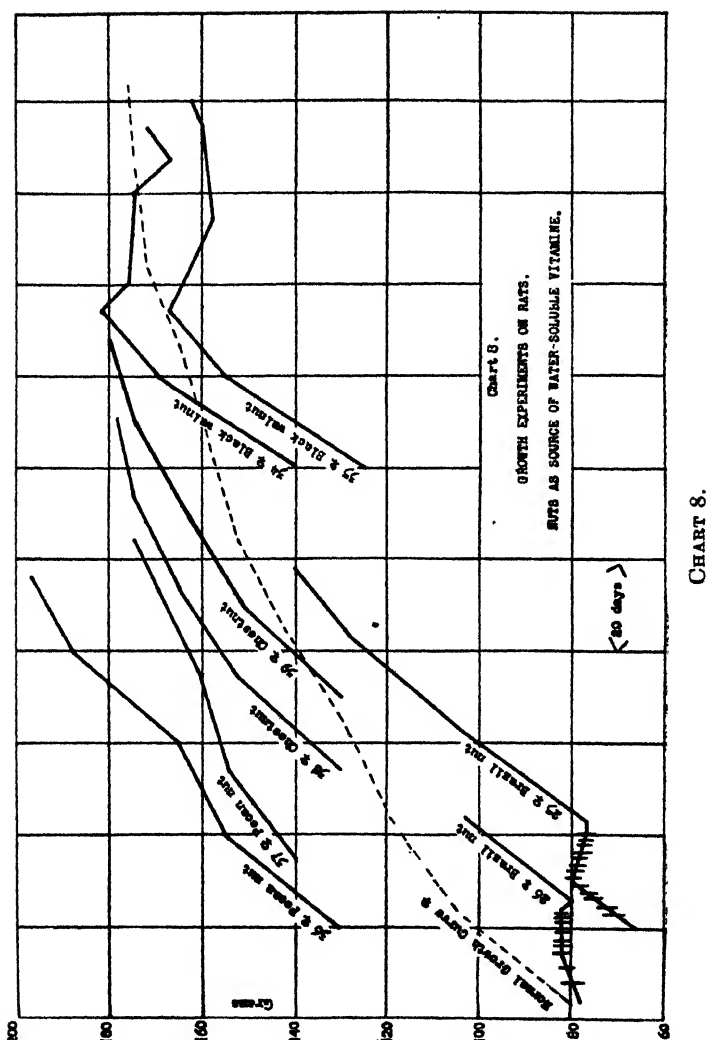


CHART 8. Growth of young rats on a diet in which the black walnut, Brazil nut, pecan, and chestnut furnish the sole source of water-soluble vitamin. 2 gm. of the black walnut and Brazil nut were fed daily in addition to the basal ration. 1 gm. of the pecan and chestnut was fed daily in addition to the basal ration.

The chestnut was blanched before feeding. The coarser parts of the integument of the other nuts were removed.

The small vertical lines on the growth curves of Rats 25 and 26 indicate days when the animals failed to eat any of the nut given in addition to the basal ration. The prompt resumption of growth indicates the point where the diet was changed to a ration consisting of one part Brazil nut diet and two parts basal diet.

The composition of diets was as follows:

Basal Diet.

	<i>per cent</i>
Casein.....	18
Salt mixture.....	4.5
Starch.....	50.5
Butter fat.....	9
Lard.....	18

Brazil Nut Diet.

<i>Rats 25, 26.</i>	<i>per cent</i>
Brazil nut press cake.....	80
Salt mixture.....	3
Starch.....	7
Butter fat.....	5
Lard.....	5

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